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# Air Pollutant Emission Factors for Military and Civil Aircraft

Lockheed Missiles and Space Co, Inc, Huntsville, AL

Prepared for

Environmental Protection Agency, Research Triangle Park, NC Office of Air Quality Planning and Standards

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# Air Pollutant Emission Factors for Military and Civil Aircraft

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16. ABSTRACT

Using data supplied by the U.S. Navy, U.S. Air Force, USEPA Office of Mobile Source Air Pollution Control, as well as published information, tables of military aircraft fuel characteristics, aircraft classifications, military and civil times in mode, engine modal emission rates, and aircraft emission factors per landing-takeoff cycle are calculated and compiled. The data encompass 59 engines and 89 aircraft. Additional discussion includes information related to benzo[a]pyrene emissions and to hydrocarbon emissions (volatile organic) with potential to produce photochemical oxidant.

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by

D. Richard Sears

Lockheed Missiles and Space Company, Inc.
Huntsville Research and Engineering Center
P.O. Box 1103
Huntsville, Alabama 35807

Contract No. 68-02-2614

EPA Project Officer: Charles C. Masser

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## FOREWORD

When fuels are burned to extract their energy, the related pollutional impacts on our environment often require that new and increasingly more efficient pollution prevention and control methods be used. Development of such methods requires reliable information on sources.

This report examines one aspect of the transportation industry contribution to fuel combustion sources, namely aircraft engine emissions. The report presents in one place a compilation of existing data from several sources. The compilation can be used by regulatory officials and air quality planners, as well as by editors of forthcoming editions of USEPA compilations of emission factors.

For further information, contact the Air Management Technology Branch, Monitoring and Data Analysis Division, Office of Air Quality Planning and Standards.

## ABSTRACT

Using data supplied by the U.S. Navy, U.S. Air Force, USEPA Office of Mobile Source Air Pollution Control, as well as published information, tables of military aircraft, fuel characteristics, aircraft classifications, military and civil times in mode, engine modal emission rates, and aircraft emission factors per landing-takeoff cycle are calculated and compiled. The data encompass 59 engines and 89 aircraft. Additional discussion includes information related to benzo[a]pyrene emissions and to hydrocarbon (volatile organic) emission with potential to produce photochemical oxidant.

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# 1. INTRODUCTION

Federal, state and local government environmental officials concerned with air quality planning and standards require reliable emission factor data for emission inventory calculations. This is true also for various public and private sector personnel performing site-specific environmental impact analyses related to proposed and on-going developments.

For these persons, the USEPA document "Compilation of Air Pollutant Emission Factors (AP-42)" (Ref. 1) has become a standard tool. For AP-42 to remain a useful document, periodic updating and occasional improvements in the quality and useful detail of its tables are necessary.

The AP-42 Section 3.2.1: "Off-Highway, Mobile Sources-Aircraft" received its last update in April 1973. Since that time, great improvements have been made in the quality and volume of available aircraft engine emission data. This is particularly true for military aircraft. Furthermore, there have been significant changes in the composition of the U.S. military aircraft inventory since 1973.

This report is intended to be a background document to support a new edition of Section 3.2.1 of AP-42. It contains a greater volume of detailed information than that which will appear in AP-42. This will permit an interested reader: (a) to calculate aircraft emission factors for some aircraft not included therein; (b) to appreciate the quantitative variations arising from different selections of engine and operating parameters; and (c) to appraise the validity of the data presented in AP-42.

The bulk of this report is concerned with military aircraft. Recent data supplied by the USEPA Office of Mobile Source Air Pollution Control (Ref. 2) are included in order to permit this document to serve as background for both civil and military portions of Section 3.2.1 of AP-42.

## 2. FLEET STATISTICS

Current military aircraft inventories are not normally released in documents of this type. Historical production data and older inventory data are irrelevant to current air quality assessments, and these are excluded. Inventory compositions at specific military and joint-use metropolitan airports vary with procurements and mission assignments, and compilation of these data would be outside the scope of this report.

By contrast, commercial carrier fleet summaries are easily available. Table 2-1 was assembled from published data (Refs. 3, 4 and 5) as described in the footnote in order to aid selection of aircraft for inclusion in this report. Such data may be used to judge the national significance of particular aircraft, but are irrelevant to local conditions.

Many of the aircraft listed in Table 2-1 see widespread or even predominant use in general aviation. No attempt was made to assemble use statistics for aircraft in general aviation service.

TABLE 2-1. FIXED WING AIRCRAFT IN COMMERCIAL CARRIER SERVICE – 1977 (REF. 3, 4, 5)*

| Jets | | Turboprops | | Piston | |
|---|---|---|---|---|---|
| Model | No. | Model | No. | Model | No. |
| 727 | 843 | CV 580 | 68 | Cessna Twins | 40 |
| DC-8 | 340 | Twin Otter | 66 | Heron | 31 |
| DC-9 | 295 | Beech 99 | 52 | DC-3 | 28 |
| 707 | 256 | F22/FH227 | 39 | Piper Twins | 25 |
| 737 | 166 | Electra | 28 | Cessna Singles | 15 |
| DC-10 | 130 | YS-11 | 21 | Islander | 12 |
| 747 | 109 | Goose | 20 | Martin 404 | 12 |
| L1011 | 82 | Metroliner | 19 | Misc. | 39 |
| Falcon | 32 | Hercules | 15 | | |
| BAC-111 | 30 | CV 600/640 | 12 | | |
| 720 | 18 | Misc. | 26 | | |

*"Commercial Carrier Service" includes all scheduled and charter passenger and freight service lines which could be identified as operating wholly or substantially within the 50 states. Categories include: domestic trunk, regional and local service, commuter, scheduled intrastate, and miscellaneous (including charter). Data are as reported in May 1977.

# 3. COMPOSITION OF ENGINE EMISSIONS

## 3.1 CRITERIA POLLUTANTS

Tables of air pollutant emission factors normally report carbon monoxide (CO), oxides of nitrogen ($NO_x$ reported as $NO_2$), hydrocarbons (reported as $CH_4$), oxides of sulfur ($SO_x$ and $H_2SO_4$, reported as $SO_2$), and particulates when available or calculable. All $SO_x$ data were calculated from engine fuel consumption rates ("fuel rates") by material balance, assuming complete conversion of sulfur to $SO_x$. Within the precision claimed, this may be correct. Nevertheless, data for $SO_x$ should be regarded as worst-case figures. The method of calculation is described in the footnotes to Tables 5-1 and 5-2. Fuel composition and specifications are discussed in Section 3.4.

## 3.2 'HYDROCARBON' (VOLATILE ORGANIC) CONSTITUENTS

In order to assess the impact of airport operations upon the local formation of photochemical smog (for which a National Ambient Air Quality Standard exists), it is necessary to know the composition of the "total hydrocarbon" fraction of aircraft emissions. In this context, "hydrocarbon" is more properly referred to as volatile organic and includes, for example, aldehydes. Insufficient specific detail is known on the subject. Trijoinis and Arledge (Ref. 6) have reviewed the available data, have made some working assumptions based on their review, and have attempted to quantitatively classify engine emissions into a 5-group reactivity scheme. Their ratings are based on the oxidant production potential of organics in each class, as determined experimentally by EPA (Ref. 7) in smog chamber tests, and upon data published by Groth and Robertson (Ref. 8) and by Chase and Hurn (Ref. 9). The reader may consult Ref. 6 for more detailed discussions. The Trijonis and Arledge results are reproduced in Tables 3-1 and 3-2, and in more detail in Appendix A.

The working assumptions implicit in these tables are that the composition of the hydrocarbon fraction is independent of engine type and of fuel composition. The first is unproved; the second is unlikely. Further, Table 3-2 was derived from Table 3-1 using assumptions and methods not described by the authors in Ref. 6. It seems constructive to present the Trijonis and Arledge results, so that the reader may apply them to subsequent data in this report as and if useful and applicable.

Methods of reporting total hydrocarbon (THC), i.e., volatile organic, concentration vary and are not always specified. The flame ionization

TABLE 3-1. DISTRIBUTION OF ORGANICS BY NUMBER OF CARBON ATOMS – TURBINE ENGINES (REFS. 6 AND 9).

| Carbon Number | Mole % of Total Organics | | | | | |
|---|---|---|---|---|---|---|
| | Idle | | Takeoff | | Approach | |
| 1 | 2 | | 3 | | 3 | |
| 2 | 6 | 11 | 0 | 3 | 1 | 5 |
| 3 | 3 | | 0 | | 1 | |
| 4 | 2 | | 1 | | 1 | |
| 5 | 2 | 11 | 3 | 5 | 2 | 5 |
| 6 | 7 | | 1 | | 2 | |
| 7 | 8 | | 1 | | 7 | |
| 8 | 7 | 38 | 13 | 33 | 14 | 33 |
| 9 | 11 | | 6 | | 2 | |
| 10 | 12 | | 13 | | 10 | |
| 11 | 9 | | 5 | | 5 | |
| 12 | 8 | | 4 | | 4 | |
| 13 | 7 | | 4 | | 3 | |
| 14 | 5 | 40 | 5 | 59* | 4 | 57 |
| 15 | 3 | | 3 | | 4 | |
| 16 | 2 | | 3 | | 3 | |
| 17 | 1 | | 4 | | 4 | |
| 18 | 1 | | 3 | | 3 | |
| 19+ | 4 | | 30 | | 27 | |
| Weight % Aldehydes relative to total hydrocarbons | 10% | | 30% | | 57% | |

*Inconsistency in source from which quoted.

TABLE 3-2. APPROXIMATE DISTRIBUTION BY ORGANIC TYPE IN CARBON NUMBER CATEGORIES – TURBINE ENGINES (REF. 6).

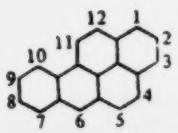
| Carbon Number Category | Type of Compounds | Taxi-Idle Mode | Takeoff Mode | Approach Mode |
|---|---|---|---|---|
| 1-3 | Paraffins | 7 | 2 | 1 |
| | Acetylene | 1 | 0 | 0 |
| | Olefins | 2 | 0 | 1 |
| | Aldehydes | 1 | 1 | 3 |
| 4-6 | Paraffins | 7 | 2 | 1 |
| | Olefins | 2 | 1 | 0 |
| | Aldehydes | 1 | 2 | 3 |
| | Benzene | 1 | 0 | 1 |
| 7-10 | Paraffins | 19 | 17 | 17 |
| | Olefins | 7 | 7 | 3 |
| | Aldehydes | 4 | 3 | 7 |
| | n- & sec- alkylbenzenes | 4 | 3 | 3 |
| | Dialkylbenzene | 4 | 3 | 3 |
| 11+ | Paraffins | 12 | 6 | 23 |
| | Olefins | 8 | 12 | 6 |
| | Aldehydes | 4 | 17 | 17 |
| | tert-alkylbenzenes | 4 | 6 | 0 |
| | n- & sec- alkylbenzenes | 4 | 6 | 5 |
| | Dialkylbenzenes | 4 | 6 | 6 |
| | Tri- and tetra-alkyl-benzenes | 4 | 6 | 0 |
| | | 100% | 100% | 100% |

detector commonly used to measure THC is basically a carbon counter. To calculate a mass emission rate, kg/hr, an assumption must be made as to x in the equivalent formula ($CH_x$) of the exhaust gas. Historically, THC has often been expressed as methane ($CH_4$) equivalent. It is our understanding that all Dept. of Defense supplied and all USEPA supplied data (Ref. 2) are expressed as $CH_4$ equivalent, except for USEPA data for General Electric engines. These are expressed as $CH_{1.8}$ (the fuel value). The latter can be converted to methane equivalent by multiplying by 1.159.

The reader must be aware, therefore, that there may be uncertainties of about 14% in the reporting basis of volatile organics. However, to place this in perspective: sampling and analysis errors, uncertainties and variations in engine power levels, variations in aircraft operating procedures, and even imprecisions in dispersion modeling can be sustantial. Their combined effects may be considerably greater than uncertainties in the reporting base for THC emissions.

## 3.3 BENZO[a]PYRENE

Although the term benzo[a]pyrene (BaP) is now often used loosely for the whole group of polynuclear (polycyclic) aromatic hydrocarbons and their derivatives, we refer here specifically to the substance whose structural formula is:




BaP is rated as among the most carcinogenic chemical compounds to which man is exposed (Refs. 11 and 12). In populous regions of the U.S., the major sources are known to be residential hand-stoked coal and wood combustion, waste combustion, and coke production (150 to 600 tons/yr). In the second rank are mobile sources (10 to 20 ton/yr), including automotive.

Apparently aircraft piston and turbine engines have not been surveyed (Ref. 11). However, a priori considerations force us to believe that turbine engines must emit BaP. As a general rule, BaP production occurs (Ref. 11):

- In any combustion producing CO
- In any process producing gray or black smoke
- In any combustion or pyrolysis at $\geq$ 500 F known to be oxygen deficient ("substoichiometric" in oxygen).

Some members of the National Research Council Committee on Biologic Effects of Atmospheric Pollutants (Ref. 12) state that aircraft probably produce annually in the order of twice as much BaP as gasoline powered automobiles – in other words, approximately 20 tons per year.

Piston engine aircraft, which lack emission control devices, may have emission factors approximating those of uncontrolled postwar cars, namely approximately 170 μg BaP per gallon of fuel consumed. Reference 11 contains a quantitative discussion of the dramatic improvements in BaP emission factors resulting from emission controls, and of the effect of engine age upon BaP releases.

## 3.4 FUEL COMPOSITION

Fuel contaminants, additives, and physical characteristics can affect combustion processes and emission rates. Some relevant research has been reported. Tables 3-3, 3-4 and 3-5 contain some incomplete data on specifications, test data, and national averages for turbine engine fuel and aviation gasoline.

Aside from matters related to performance and reliability, fuel modifications or substitutions impact emissions and involve trade-offs with other non-environmental goals. Figure 3-1, due to Grobman, et al., (Ref. 17), emphasizes some of these tradeoffs.

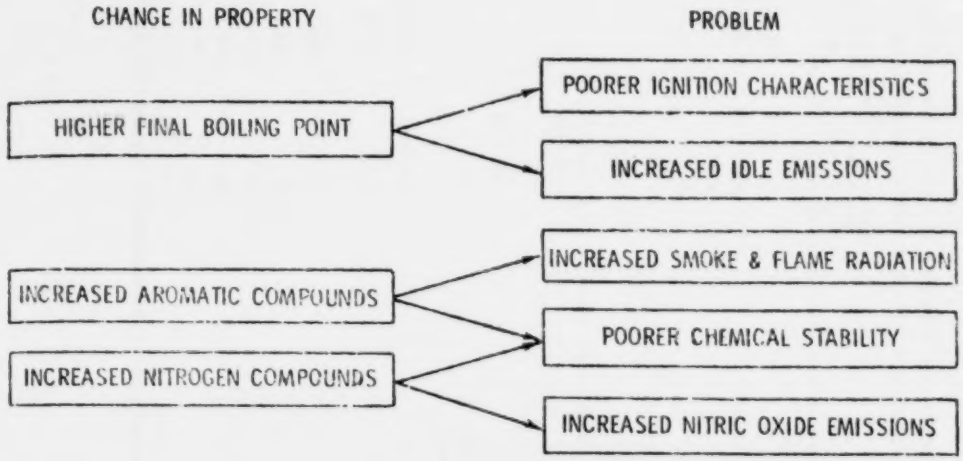



Figure 3-1. Problems associated with altered fuel characteristics (Ref. 17).

TABLE 3-3. SPECIFICATIONS FOR RELEVANT PROPERTIES OF JET FUELS (REFS. 13, 14, 15 AND 31)

| Property | JP-4 | | JP-5 | | Jet A | Jet B |
|---|---|---|---|---|---|---|
| | MILSPEC MIL-T-5624 | Representative Actual | MILSPEC MIL-T-5624 | Representative Actual | ASTM D-1655 | ASTM D-1655 |
| Composition | | | | | | |
| Hydrogen, wt% | — | 14.31 | — | 13.79 | | |
| Sulfur, wt% (max) | 0.4 | 0.072 | | | 0.3 | 0.3 |
| Mercaptan sulfur, wt% (max) | 0.001 | | 0.001 | | 0.003 | 0.003 |
| Aromatics, vol% (max) | 25.0 | 14.8 | | | 20.0 | 20.0 |
| Olefins, vol% (max) | 5.0 | 0.6 | 5.0 | | 5.0 | 5.0 |
| Fuel System Icing Inhibitor, vol% (min/max) | 0.10/0.15 | | | | | |
| Anti-oxidants (Blended Separately or in Combination) (max) | 9.1 g/100 gal | | | | | |
| 2, 6 – di-tert-butylphenol | 75% min | | | | | |
| 2, 6 – di-tert-butyl-4-methylphenol | — | | | | | |
| 2, 4 – dimethyl-6-tert-butyl phenol<br>tri-tert-butylphenols | 25% max | | | | | |
| N, N' – diisopropyl-p-phenylenediamine | — | | | | | |
| N, N' – di-sec-butyl-p-phenylenediamine | — | | | | | |
| Heat of Combustion, Btu/lb (min) | 18,400 | 18,622 | 18,300 | 18,444 | 18,400 | 18,400 |
| Smoke Point (min) | — | 28.0 | | | | |
| ASTM Distillation: | | | | | | |
| Initial Boiling Point, °F | — | 164 | — | 330 | — | — |
| 10% max °F | — | 202 | 400 | 371 | 400 | — |
| 20% max °F | 290 | 218 | — | 384 | — | 290 |
| 50% max °F | 370 | 266 | — | 407 | 450 | 370 |
| 90% max °F | 470 | 393 | — | 450 | — | 470 |
| Final Boiling Point, °F (max) | — | 470 | 550 | 480 | 550 | — |

TABLE 3-4. 1976 U.S. NATIONAL DATA FOR AVIATION TURBINE ENGINE FUELS (REF. 13)

| | Jet A | Jet B | JP4 | JP5 |
|---|---|---|---|---|
| No. Samples Analyzed | 65 | 5 | 33 | 8 |
| S, wt% | 0.60 | 0.041 | 0.042 | 0.059 |
| Mercaptan, wt% | 0.0009 | 0.0005 | 0.0005 | 0.0004 |
| Olefins, vol% | 1.1 | 0.9 | 0.9 | 0.8 |
| Aromatics, vol% | 17.0 | 10.6 | 11.2 | 16.9 |

TABLE 3-5. COMPOSITION OF AVIATION GASOLINE (REFS. 14, 16)

| | Mil Spec[a] | 1963 Measurements |
|---|---|---|
| S, wt% | 0.05 | $\leq$ 0.01 |
| Aromatics | | |
| 80/87 | – | |
| 100/130 | – | |
| 115/145 min | 5.0 | |

[a]MIL-G-5572E Amend. 2, May 1975.

Figure 3-2 shows the relationship between visible emissions (reported as SAE smoke number) and hydrogen content of the fuel, which in turn varies approximately inversely as the aromatics content (Ref. 17). $NO_x$ emissions are not very sensitive to fuel nitrogen content, since most $NO_x$ is produced by oxidation of atmospheric nitrogen in combustion air. Grobman, et al., (Ref. 17) give an example in which an 80-fold increase in fuel nitrogen caused an 18% increase in $NO_x$ emission. Engine operating and design parameters (e.g., fuel-air ratio and inlet temperature) have more affect on $NO_x$ production.

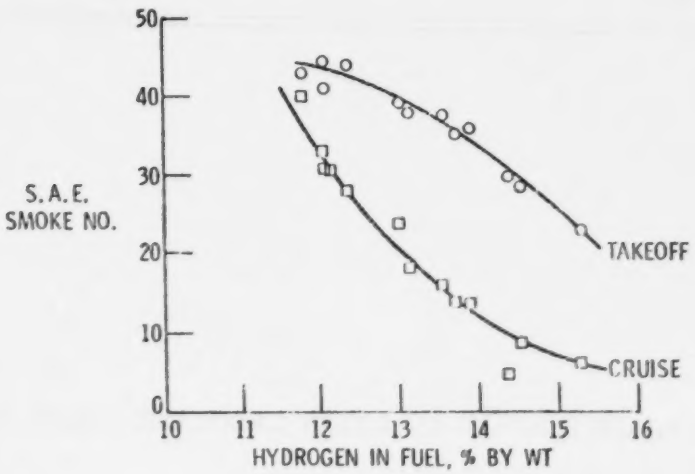



Figure 3-2. Effect of fuel hydrogen content upon visible emissions (Ref. 17).

Volatile organic emissions result from several airport operations apart from engine operation. Examples are: fuel transfer, spillage, storage, operation of auxiliary power units, and engine maintenance. Fuel volatility not only effects engine performance, but also fugitive emissions. Figure 3-3 presents a schematic comparison of fuel volatility, expressed as boiling ranges.

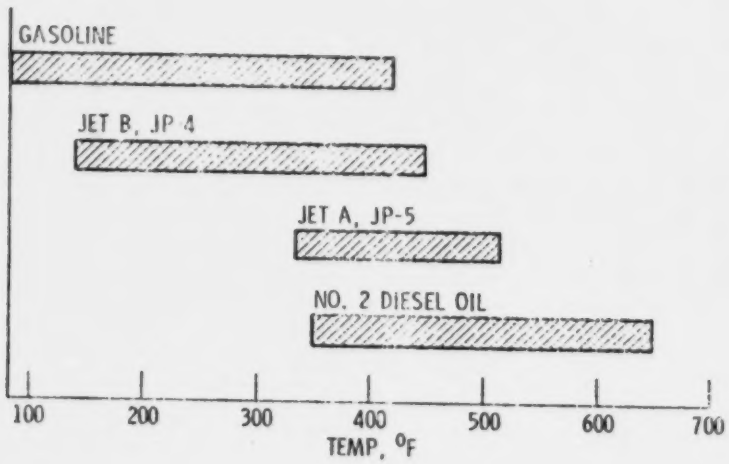



Figure 3-3. Boiling range of various petroleum products (Ref. 17)

# 4. DEVELOPMENT OF THE EMISSION TABLES

## 4.1 SELECTION AND CULLING OF DATA

Civil aircraft emission data reported in later sections were received from the USEPA Office of Mobile Source Air Pollution Control, Ann Arbor, Mich., (Ref. 2, 20). On the basis of the data reported earlier in Table 2-1, the BAC-111 has been added to the Commercial Carrier Jet Category, and the entire category of Air Carrier Turboprops has been added. The Dassault Falcon 20 has been added to the General Aviation category. Several more aircraft definitely deserved listing on the basis of frequency of use; however, engine emission data were not available. Two examples are the venerable DC-3 and the Martin 404.

Selection of military engines and aircraft was the most time-consuming task in this project. A very large number of distinct engines and aircraft exist, and a very large volume of emissions data are available, principally in the U.S. Navy's emissions data compendium (Ref. 21). The data presented were culled from information on 1000 military aircraft models and variations. Engines surveyed included 82 models and 424 series: 19 models and 181 series of turbojets; 14 models and 38 series of turbofans; 10 models and 45 series of turboprops; 16 models and 54 series of turboshafts; 14 models and 46 series of opposed piston engines; and 9 models and 60 series of radial piston engines.

Emission data were not available for all of these. Further, most aircraft had several alternative engines. Because inventory data were not available, we were not necessarily able to select the most common model/series engine for each model/variation of aircraft. Frequently we had to be satisfied with listing an engine known to be representative, if not necessarily the most commonly installed in a given aircraft.

To cull the data we used 5 x 8 in. double-row edge-notch cards designed for manual sorting.

Aircraft cards were entered with:

Model/Variation
Popular Name
Mission
Number of Engines
Engine Type
Engine Model/Series

Service Using
Whether Fixed Wing or Rotary
Whether Emission Data were Available.

These cards were edge-notch coded for each option of mission, engine, etc.

Engine cards contained entries for:

Type
Model/Series
Aircraft Types on Which Used
Service in Which Used
Whether Emission Data were Available.

Using these sorting cards, we were able to select a list of aircraft model/variations with engine model/series representative of those aircraft, and requiring a minimum number of engines for compilation in the modal emission rate tables (cf., later sections). This list was expanded somewhat to include aircraft variations displaying significantly different emissions characteristics because of engine choice, mission, service, characteristics, etc. An example would be the inclusion of both the B52G and B52H bombers, and two versions of the A7 Corsair 2 attack aircraft.

The culling process was assisted by our use of several non-military publications (Refs. 22 and 23), in addition to military and civilian experts (Refs. 24 through 30).

Standard annual publications in this field are the Aerospace Forecast and Inventory Issue, "Aviation Week and Space Technology," (Ref. 22) and the huge Jane's All the Worlds Aircraft (Ref. 23).

## 4.2 MILITARY AIRCRAFT CLASSIFICATION

The result of the sorting discussed in the preceding section is displayed in Table 4-1. Entries are largely self-explanatory, except perhaps for the power plant type designation. The following discussion is largely from Masser (Ref. 1).

Aircraft engines are of two major categories: reciprocating (piston) and gas turbine.

The basic element in the aircraft piston engine is the combustion chamber, or cylinder, in which mixtures of fuel and air are burned and from which energy is extracted through a piston and crank mechanism that drives a propeller. The majority of aircraft piston engines have two or more cylinders and are generally classified according to their cylinder arrangement – either "opposed" or "radial." Opposed engines are installed in most light or utility aircraft; radial engines are used mainly in large transport aircraft. Almost no single-row inline or V-engines are used in current aircraft. The gas turbine engine in general

TABLE 4-1. MILITARY AIRCRAFT CLASSIFICATIONS (REFS. 21, 22, 23)

| Aircraft Mission (Class) | DOD Designation | Popular Name | Manufacturer[a] | Service | Power Plant | | | | Other Versions and Related Military Aircraft Included and Civil Equivalents |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | No. & Type[b] | Mfg[a] | Designation | Afterburner? | |
| | | | FIXED WING | | TURBINE | | | | |
| Attack | A-4 | Skyhawk | McD-Doug | USN, USMC | 1 TJ | P&W | J52, J65 | | TA-4 |
| | A-6 | Intruder | Grumman | USN | 2 TJ | P&W | J52 | | EA-6, KA-6 |
| | A-7 | Corsair 2 | Vought | USN | 1 TF | All, P&W | TF 41, TF30 | No | TA7 |
| | AV-8A | Harrier | Hawk-Sid | USMC | 1 TF | RR | F402 | No | TAV8 |
| | A-10 | -------- | Fairch-Rep | USAF | 2 TF | GE | TF34 | No | |
| | A37 | Dragonfly | Cessna | USAF | 2 TJ | GE, Con. | J85, J69 | No | |
| Bomber | B-52 C-G | Stratofortress | Boeing | USAF | 8 TJ | P&W | J57 | No | |
| | B-52H | Stratofortress | Boeing | USAF | 8 TF | P&W | TF33 | No | |
| Fighter | F-4 | Phantom 2 | McD-Doug | USAF, USN | 2 TJ | GE | J79 | Yes | RF-4 |
| | F-5 | Freedom Fighter (Tiger 2) | Northrop | USAF | 2 TJ | GE | J85 | Yes | |
| | F-8 | Crusader | Vought | ANG | 1 TJ | P&W | J57 | | TF-8, RF-8 |
| | F-14 | Tomcat | Grumman | USN | 2 TF | P&W | TF30, F401 | Yes | |
| | F-15A | Eagle | McD-Doug | USAF | 2 TF | P&W | F100 | Yes | TF 15 |
| | F-16 | -------- | GD/FW | USAF | 1 TF | P&W | F100 | Yes | |
| | F-100 | Super Sabre | No. Amer. | ANG | 1 TJ | P&W | J57 | Yes | |
| | F-106 | Delta Dart | GD/Convair | USAF | 1 TJ | P&W | J75 | Yes | |
| | F-111 | -------- | GD/FW | USAF | 2 TF | P&W | TF30 | Yes | FB-111, EF-111A |
| | F-18 | Hornet | Northrop & McD-Doug | USN, USMC | 2 TF | GE | F404 | | YF-17, TF-18 |
| Cargo/Tanker/ Transport | C-2 | Greyhound | Grumman | USN | 2 TP | All | T56 | No | E-2 |
| | C-5A | Galaxy | GELAC | USAF | 4 TF | GE | TF39 | No | |
| | C-9 | Nightingale (Skytrain 2) | McD-Doug | USAF, USN | 2 TF | P&W | JT8D | No | VC-9; (DC-9 Equiv.) (Super King Air 200) |
| | C-12 | Huron | Beech | USAF, USA | 2 TP | PWC | PT6A | No | |
| | C-130 | Hercules | GELAC | USAF, USN, USCG | 4 TP | All | T56 | No | DC, HC, RC, EC, AC, WC Versions |

[a] Abbreviations: All – Detroit Diesel Allison Division of General Motors; CAE – Teledyne CAE (Continental); CALAC – Lockheed-California; Con – Continental; Fairch-Rep – Fairchild Republic; GA – Garrett AiResearch; GD/FW – General Dynamics, Ft. Worth; GE – General Electric; GELAC – Lockheed-Georgia; Hawk-Sid – Hawker Siddeley (UK); Helio/GA – Helio General Aircraft; Lyc – Lycoming; McD-Doug – McDonnell Douglas; P&W – Pratt & Whitney; PWC – Pratt & Whitney Aircraft of Canada; RI/Columbus – Rockwell International, Columbus; RI/GA – Rockwell International, General Aviation; RR – Rolls Royce; Wr – Curtiss Wright

[b] TJ – Turbojet; TF – Turbofan; TP – Turboprop; TS – Turboshaft; R – Reciprocating (Piston), Radial; O – Reciprocating (Piston), Opposed.

TABLE 4-1. (CONTINUED)

| Aircraft Mission (Class) | DOD Designation | Popular Name | Manufacturer[a] | Service | Power Plant | | | | Other Versions and Related Military Aircraft Included and Civil Equivalents |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | No. & Type[b] | Mfg[a] | Designation | Afterburner? | |
| | | | FIXED WING | | TURBINE | | | | |
| Cargo/Tanker/ Transport | KC-135 | Stratotanker | Boeing | USAF | 4 TJ | P&W | J57 | No | C, EC, RC Versions |
| | C-140 | Jet Star | GELAC | USAF, USN | 4 TJ | P&W | J60 | No | VC-140 |
| | C-141 | Starlifter | GELAC | USAF | 4 TF | P&W | TF33 | No | |
| Trainer | T-2 | Buckeye | RI/Columbus | USN | 2 TJ | GE | J85, J34, J60 | | |
| | T-34C | Turbo Mentor | Beech | USN | 1 TP | PWC | PT6A | No | (See T34 A/B Mentor) |
| | T-37 | Tweet | Cessna | USAF | 2 TJ | CAE | J69 | No | |
| | T-38 | Talon | Northrop | USAF | 2 TJ | GE | J85 | Yes | |
| | T-39 | Sabreliner | RI/GA | USAF, USN | 2 TJ | P&W | J60 | No | CT39 |
| | T-44 | -------- | Beech | USN | 2 TP | PWC | PT6A | No | VC6B; (King Air 90) |
| Observation Patrol/Antisub, Early Warning | OV-1 | Mohawk | Grumman | USA | 2 TP | Lyc | T53 | No | RV-1 |
| | OV-10 | Bronco | RI/Columbus | USA | 2 TP | GA | T73 | No | |
| | P-3C | Orion | CALAC | USN | 4 TP | All | T56 | No | (Electra) |
| | S-3A | Viking | CALAC | USN | 2 TF | GE | TF34 | No | |
| | E-2 | Hawkeye | Grumman | USN | 2 TP | All | T56 | No | |
| | E-3A | AWACS | Boeing | USAF | 4 TF | P&W | TF33 | No | |
| Utility | U-21 | Ute | Beech | USA | 2 TP | PWC | T74, PT6A | No | RU21, (King Air A90, A100) |
| | AU-23 | Peacemaker | Fairchild | USAF | 1 TP | GA | TPE331-1 | No | |
| | AU-24 | Stallion | Helio/GA | USAF | 1 TP | PWC | PT6A | No | |

TABLE 4-1. (CONCLUDED)

| Aircraft Mission (Class) | DOD Designation | Popular Name | Manufacturer[a] | Service | Power Plant: No. & Type[b] | Mfg.[b] | Designation | Afterburner? | Other Versions and Related Military Aircraft Included and Civil Equivalents |
|---|---|---|---|---|---|---|---|---|---|
| | | | FIXED WING | | PISTON | | | | |
| Cargo/Tanker/ Transport | C-1 | Trader | Grumman | USN | 2 R | Wr | R-1820 | | S-2D |
| Trainer | T-28 | Trojan | RI/Columbus | USN | 1 R | Wr | R-1820, 1300 | | |
| | T-29 | Flying Classroom | CALAC | USN | 2 R | P&W | R-2800 | | |
| | T-34 | Mentor | Beech | USN | 1 O | Con | O-470 | | (See T-34C Turbomentor) |
| | T-41 | Mescelero | Cessna | USA | 1 O | Con | IO-360 | | (Cessna 172-Skyhawk) |
| | T-42 | Cochise | Beech | USA | 1 O | Con | IO-470 | | (Baron B-55) |
| Observation | O-1 | Bird Dog | Cessna | USA | 1 O | Con | O-470 | | |
| | O-2 | -------- | Cessna | USAF | 2 O | Con | IO-360 | | |
| | S-2 | Tracker | Grumman | USN | 2 R | Wr | R-1820 | | E1B, C1A |
| Utility | U-4 | Aero Commander | RI/GA | USA | 2 O | Lyc | GSO-480 | | U-9 |
| | U-8 | Seminole | Beech | USA | 2 O | Lyc | O-480, IGSO-480 | | (Twin Bonanza E-50; Queen Air 65) |
| | U-10 | Courier | Helio/GA | USA | 1 O | Lyc | GO-480 | | |
| | | | ROTARY WING | | | | | | |
| Utility | UH-1H | Iroquois ("Huey") | Bell Heli | USA, USN | 1 TS | Lyc, GE | T53, T58 | | UH-1A/B/C/D/E/F/L; HH-1H, K |
| Utility | UH-1N | Twin Huey | Bell Heli | USAF, USN, USMC | 2 TS | PWC | T400 | | |
| Attack | AH-1G | Hueycobra | Bell Heli | USN | 1 TS | Lyc, PWC | T53, T400 | | AH1J, UH-1G, TH-1G |
| Antisub | SH-2D/F | Seasprite | Kaman | USN | 2 TS | GE | T58 | | (UH-2A/B/C have one T58) |
| Search/Rescue | HH-3 | Sea King "Jolly Green Giant" | Sikorsky | USAF, USN, USCG | 2 TS | GE | T58 | | CH, RH, SH, UH, VH versions |
| Observation | OH-6A | Cayuse | Hughes Heli | USA | 1 TS | All | T63 | | |
| Search/Rescue | HH-43 | Huskie "Mixmaster" | Kaman | USAF | 1 TS | Lyc | T53 | | UH-46 |
| Cargo | CH-46 | Sea Knight | Boeing Vertol | USA, USN | 2 TS | GE | T58 | | |
| Cargo | CH-47 | Chinook | Boeing Vertol | USA | 2 TS | Lyc | T55 | | |
| Search/Rescue | HH-52 | -------- | Sikorsky | USN | 1 TS | GE | T58 | | |
| Cargo | CH-53 | Sea Stallion | Sikorsky | USAF, USN | 2 TS | GE | T64 | | RH, VH versions |
| Search/Rescue | HH-53 | Super Jolly | Sikorsky | USAF | 2 TS | GE | T64 | | |
| Cargo | CH-54 | Tarhe | Sikorsky | USA | 2 TS | P&W | JFTD-12A | | |
| Trainer | TH-55 | Osage | Hughes | USA | 1 O | Con | H10-360 | | (Hughes 300) |
| Trainer | TH-57 | Sea Ranger | Bell Heli | USN | 1 TS | All | 250-C18 | | |
| Observer | OH-58 | Kiowa | Bell Heli | USA | 1 TS | All | T63 | | |

consists of a compressor, a combustion chamber, and a turbine. Air entering the forward end of the engine is compressed and then heated by burning fuel in the combustion chamber. The major portion of the energy in the heated air stream is used for aircraft propulsion. Part of the energy is expended in driving the turbine, which in turn drives the compressor. Turbofan and turboprop or turboshaft engines use energy from the turbine for propulsion; turbojet engines use only the expanding exhaust stream for propulsion. The terms "propjet" and "fanjet" are sometimes used for turboprop and turbofan, respectively.

The fact that a particular aircraft is not listed in Table 4-1 does not imply that emission factors cannot be calculated. It is the engine emissions and the time-in-mode category which determine emissions. If these are known, emission factors can be calculated in the same way that the following tables were developed (cf., Sections 4-3 and 4-4).

Frequently aircraft will be identified by popular name rather than model. Table 4-2 can be used to determine model numbers and representative engines. To select an appropriate time-in-mode category, the aircraft mission must be known. A standardized nomenclature exists for military aircraft (Ref. 21). Deviations from this nomenclature are frequent, however.

| Mission Symbol | Mission |
|---|---|
| A | Attack Aircraft |
| B | Bomber Aircraft |
| C | Cargo/Transport Aircraft |
| D | Director Aircraft |
| E | Special Electronic Installation Aircraft (Early Warning) |
| F | Fighter Aircraft |
| H | Search/Rescue Aircraft |
| K | Tanker Aircraft |
| L | Cold Weather Aircraft |
| N/J | Special Test Aircraft |
| O | Observation Aircraft |
| P | Patrol Aircraft |
| Q | Drone Aircraft |
| R | Reconnaissance Aircraft |
| S | Anti-Submarine Aircraft |
| T | Trainer Aircraft |
| U | Utility Aircraft |
| V | Staff Aircraft |
| W | Weather Aircraft |
| X | Research Aircraft |

Example:

U H - 2 B

Basic Mission Symbol (Utility Aircraft)
Type Symbol (Helicopter Type)
Design Number (2nd Type Helicopter)
Series Letter (2nd Series)

TABLE 4-2. CROSS REFERENCE OF POPULAR OR UNOFFICIAL NAMES WITH MILITARY DESIGNATIONS (REFS. 21, 22, 23, 24)

| Popular Names | Model Designation | Basic Engine | Cognizant Service |
|---|---|---|---|
| AAH | YAH-64 | T700 | Army |
| Academe | TC-4C | MK529 | Navy |
| Advanced Harrier | AV-8B | RR Pegasus 11 | USMC |
| Aero Commander | U-4/U-9 | GO-480 | AF |
| Albatross | HU-16 | R-1820 | Navy/AF/USCG |
| AWACS | E-3A | TF33 | AF |
| Aztec | U-11 | O-540 | Navy |
| Beaver | U-6 | R-985 | AF/Army/Navy |
| Bird Dog | U-1 | O-470 | Army |
| Blackbird | SR-71 | J58 | AF |
| Bronco | OV-10 | T76 | AF/Navy |
| Buckeye | T-2 | J34/J60/J85 | Navy |
| Canberra | B-57 | J65/TF33 | AF |
| Cargo Master | C-133 | T34 | AF |
| Caribou | C-7A | R-2000 | AF |
| Cayuse | OH-6A | T-63 | Army |
| Cheyenne | AH-56A | T64 | Army |
| Chickasaw | H-19 | R-1300/1340 | AF |
| Chinook | CH-47 | T55 | Army |
| Choctaw | CH-34 | R-1820 | AF/Army |
| Chochise | T-42A | IO-470 | Army |
| Cobra | See Hueycobra | | USN |
| Cobra | F-18L | F404 | USN |
| Commando | C-46 | R-2800 | AF |
| Constellation | C-121A | R-3350 | AF/Navy |
| Corsair II | A-7 | TF41 | Navy |
| Cougar | F-9 | J48 | Navy |
| Courier | U-10 | GO-480 | AF |
| Crusader | F-8 | J57 | Navy |
| Dash | QH-50C | T50 | Navy |
| DC-3 | See Sky Train | | |
| Delta Dagger | F-102 | J57 | AF |
| Destroyer | RB-66 | J71 | AF |
| Dragonfly | A-37B | J85 | AF |
| Eagle | F-15A | F100 | AF |
| Flying Boxcar | C-119 | R-3350/4360 & J85 | AF |
| Flying Classroom | T-29 | R-2800 | AF |
| Freedom Fighter | F-5 | J85 | AF |
| Galaxy | C-5A | TF39 | AF |
| Globemaster | C-124 | R-4360 | AF |
| Greyhound | C-2 | T56 | Navy |
| Gulfstream I | C-4 | MK529 | CG |
| Gulfstream II | VC-11 | MK511 | CG |
| Harrier | AV-8A | F-402 | Navy |
| Hawkeye | E-2 | T56 | Navy |
| Hercules | C-130 | T56 | AF/Navy |
| Huey | See Iroquois | | |
| Hueycobra | AH-1G | T53/400 | Army |
| Huron | C-12A | PT6A | Army/AF |
| Huskie | H-43 | T53 | AF/Navy |
| Hustler | B-58 | J70 | AF |
| H-500 Twin | U-5A | O-540 | AF |
| Intruder | A-6 | J52 | Navy |
| Invader | A-26 | R-2800 | AF |
| Iroquois | UH-1 | T53/58/400 | Army |
| Jet Star | C-140 | T60 | AF/Navy |
| Jolly Green Giant | HH-3E | T58 | AF |

TABLE 4-2. CONTINUED

| Popular Names | Model Designation | Basic Engine | Cognizant Service |
|---|---|---|---|
| Kiowa | OH-58 | T63 | Army |
| Liftmaster | C-118 | R-2800 | AF/Navy |
| Mentor | T-34 | O-470 | AF/Navy |
| Mescalero | T-41 | O-300 | Army/AF |
| Mixmaster | See Huskie | | |
| Mohawk | OV-1 | T53 | Army |
| Mojave | CH-37 | R-2900 | AF/Navy |
| Navigator | RC-45J/UC-45J | R-985 | USN |
| Navion | U-18 | O-470 | AF |
| NEACP | E-4 | CF6-50E | AF |
| Neptune | P-2 | R-3350 & J34 | Navy |
| Nightingale | C-9 | JT8D | AF |
| Orion | P-3 | T56 | Navy |
| Osage | TH-55A | H10 | Army |
| Otter | U-1 | R-1340 | AF/Navy |
| Peacemaker | AU-23A | TPE331 | AF |
| Phantom II | F-4 | J-79 | Navy/AF |
| Provider | C-123 | R-2800 | AF |
| Prowler | EA-6B | J-52 | Navy |
| Raven | H-23 | O-335/435/540 | Army |
| Sabre | F-86 | J47/73 | AF |
| Sabreliner | T-39 | J60 | AF/Navy |
| Samaritan | C-131 | R-2800/501-D13H | AF |
| Seabat | SH-34 | R-1820 | Navy |
| Seacobra | AH-1J/T | T400 | USMC |
| Seahorse | H-34 | R-1820 | Navy |
| Sea King | H-3 | T58 | Navy |
| Sea Knight | H-46 | T58 | Navy |
| Searanger | TH-57 | 250-C18 | Navy |
| Seasprite | H-2 | T58 | Navy |
| Seastallion | CH-53 | T64 | Navy |
| Sea Star | T-1 | J33 | Navy |
| Seminole | U-8 | O-480 | Army |
| Seneca | H-41A | FSO | Army |
| Shawnee | H-21 | R-1820 | Army |
| Shooting Star | F-80/T-33 | J33 | AF/Navy |
| Sioux | H-13 | O-335/435 | Army |
| Skyhawk | A-4 | J52/65 | Navy |
| Sky Knight | F-10 | J34 | Navy |
| Skymaster | C-54 | R-2000 | AF/Navy |
| Skyraider | A-1 | R-3350 | AF/Navy |
| Skytrain I | C-47/C-117 | R-1820/2000 | AF/Navy, NG |
| Skytrain II | C-9B | JT8D | Navy |
| Skywarrior | A-3 | J57 | Navy |
| Stallion | AU-24A | PT6A | AF |
| Starfighter | F-104 | J79 | AF |
| Starlifter | C-141 | TF33 | AF |
| Stratocruiser | C-97 | R-4360 | AF |
| Stratofortress | B-52 | TF33/J57 | AF |
| Stratofreighter | KC-97 | R-4360 & J47 | AF |
| Stratojet | B-47 | J47 | AF |
| Stratolifter | C-135 | TF33/J57 | AF |
| Stratoliner | VC-137 | JT3D | AF |
| Stratotanker | KC-135 | J57 | AF |
| Super Constellation | C-121 | R-3350 | AF |
| Superfortress | B-29/B-50 | R-4360 | AF |
| Super Jolly | HH-53B/C | T64 | AF |
| Super Sabre | F-100 | J57 | AF |
| Talon | T-38 | J85 | AF |
| Tarhe | CH-54A | JFTD | Army |
| T-Bird | T-33A | J33 | AF |
| Thunderchief | F-105 | J57/75 | AF |
| Thunderflash | RF-84F/K | J65 | AF |
| Thunderstreak | F84F | J65 | AF |
| Tiger I | F-11 | J65 | Navy |
| Tiger II | F-5E | J85 | AF |

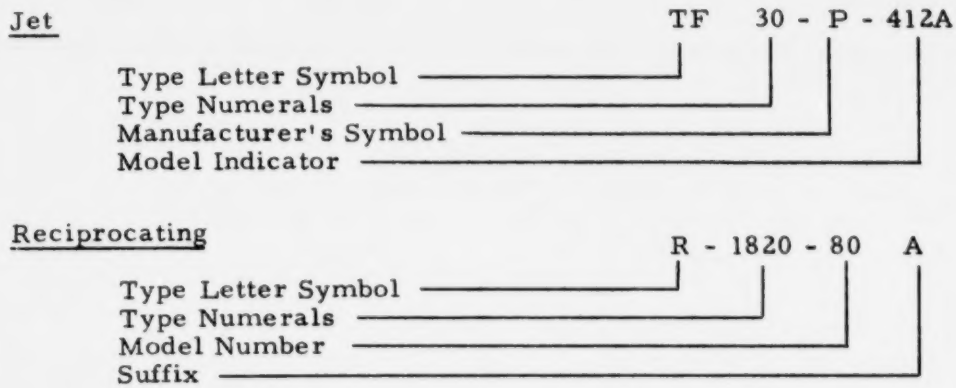
TABLE 4-2. CONCLUDED

| Popular Names | Model Designation | Basic Engine | Cognizant Service |
|---|---|---|---|
| Tomcat | F-14 | TF30/F401 | Navy |
| Tornado | B-45 | J47 | AF |
| Tracer | E-1 | R-1820 | Navy |
| Tracker | S-2 | R-1820 | Navy |
| Trader | C-1 | R-1820 | Navy |
| Trojan | T-28 | R-1820 | Navy/AF |
| Turbo Mentor | T-34C | PT6A | Navy |
| Tweet | T-37 | J69 | AF |
| Ute | U-21 | PT6A | Army |
| UTTAS | UH-60A | T700 | Army |
| U2 | U-2/WU-2 | J75 | AF/NASA |
| Vigilante | A-5 | J79 | Navy |
| Viking | S-3A | TF34 | Navy |
| Voodoo | F-101 | J57 | AF |
| Warning Star | C-121 | R-3350 | Navy |
| Workhorse | H-21 | R-1820 | AF |

Similarly, there is a standard military engine nomenclature (Ref. 21). All engines in each service have been classified into the following categories according to the type of engine as indicated by the type letter symbol:

| | |
|---|---|
| J | Turbojet |
| T | Turboprop, Turboshaft |
| F, TF | Turbofan |
| R | Radial Piston |
| O | Opposing Piston |

Examples of the jet and reciprocating engine designation systems are shown below:




Manufacturers are coded as follows:

| Symbol | Manufacturer | Example |
|---|---|---|
| A | Allison | TF41-A-2 |
| GE | General Electric | J79-GE-10 |
| P, PW | Pratt & Whitney | J57-P-420 |
| W | Curtis-Wright | J65-W-5 |
| F | Ford | J57-F-59W |
| P/F | Pratt & Whitney/Ford | J57-P/F-59W |
| W/B | Wright/Buick | J65-W/B-7C |
| L | Lycoming | T53-L-11 |
| CP | United Aircraft of Canada, Ltd | T400-CP-400 |
| G, GA | Garrett Air Research | T76-G-10 |
| R | Ranger | J44-R-3 |
| RR | Rolls-Royce, Ltd | F402-RR-401 |
| T, CA | Teledyne CAE (Continental) | J69-T-25 |
| WE | WECO/Pratt & Whitney | J34-WE-34 |
| BO | Boeing | T50-BO-4 |
| B | Buick | J65-B-5 |

## 4.3 DEFINITIONS AND LIMITATIONS

The USEPA document AP-42 (Ref. 1) defines an emission factor as:

> "an estimate of the rate at which a pollutant is released to the atmosphere as a result of some activity, such as combustion or industrial production, divided by the level of that activity (also expressed in terms of a temporal rate). In other words, the emission factor relates the quantity of pollutants emitted to some indicator (activity level) such as production capacity quantity of fuel burned, or vehicle miles traveled."

In the case of aircraft emissions, the most appropriate indicator of activity level is the complete landing-takeoff cycle. However, other choices appear in the literature (cf. Table 4-3).

All of the numerical data presented in this report were collected from other referenced sources. In most cases, the data had to be processed in order to present it here in two forms; mass of pollutant per engine per unit time (in specified modes), and mass of pollutant per aircraft per complete landing/takeoff cycle. Little uniformity of usage was observed to be practiced in the naming of the various quantities used in processing and reporting of aircraft emission data. To avoid confusion and expedite discussion, we have adopted the definitions in Table 4-3, and as follows:

"LTO cycle," the landing-takeoff cycle, incorporates all of the following flight and ground operational modes (at their times-in-mode, TIMs): descent/approach from approximately 3000 ft above ground level (AGL), and including touchdown, landing run, taxi-in, idle and shut-down, start-up and idle, check-out, taxi-out, takeoff, and climb-out to approximately 3000 ft. AGL. In order to make the volume of data manageable and to facilitate comparisons, all of these operations are conventionally grouped into just five standardized modes: taxi/idle (out), takeoff, climbout, approach, and taxi/idle (in).

"TIM," Time-in-Mode: Typical operating time spent by an aircraft in each major operating mode. For military aircraft, the TIM represents normally observed practice for the subject aircraft when operating in the continental U.S.

Some civil TIMs are specified in regulations promulgated by the USEPA, as the basis for determining compliance with mobile source emission standards (Refs. 18 and 19). The remaining civil TIMs represent experience during periods of heavy activity at large, congested metropolitan U.S. airports.

These definitions of LTO cycle and TIMs require some caveats, for the definitions have important restrictions which limit their application in non-average situations.

The use of 3000 ft AGL is a significant assumption which will be invalid at many airports. It represents an average U.S. inversion height, i.e., an

TABLE 4-3. SYMBOLS AND ACRONYMS

| Symbol | This Report | Alternatives Used Elsewhere | Definitions | Typical Units |
|---|---|---|---|---|
| 1000 $\Delta e/\Delta F$ | Mass emission rate | Emission index* | Mass of pollutant per engine per 1000 lb of fuel in specified mode | lb/1000 lb |
| $\Delta e/\Delta t$ | Modal emission rate | Modal emission factor | Mass of pollutant per engine per hr. in specified mode | lb/hr |
| – | (Not used) | Modal emission factor | Mass of pollutant per engine per mode | lb/mode |
| – | (Not used) | Engine emission factor | Mass of pollutant per engine per LTO cycle | lb/LTO cycle |
| E* | Emission factor per LTO cycle | – | Mass of pollutant per aircraft per LTO cycle | lb/LTO cycle |
| $\Delta F/\Delta f$ | Fuel rate | Fuel flow, $\dot{M}_f$ | Rate of consumption of fuel per engine per unit time in specified mode | lb/hr |
| LTO | Landing-takeoff | – | (cf. text) | – |
| TIM | Time-in-mode | – | (cf. text) | – |
| AGL | Above ground level | – | (As distinct from elevation or altitude, which can be ambiguous.) | – |

*$\Delta e/\Delta F$ corresponds to an emission factor in fuel units, as used in the National Emissions Data System (NEDS), and E corresponds to an emission factor in process units.

average mixing depth for pollutants emitted during the LTO cycle. In an area where the inversion height is actually lower than 3000 ft AFL, relevant $NO_x$ emissions can be significantly overstated and, conversely, the impact of CO and HC emissions might be understated (Ref. 36). This is because the portions of the climbout and approach modes actually spent beneath the inversion layer are the only portions which should contribute to the climbout and approach TIM's in the emission factor calculations.

Meteorologic data are available for many major military and civilian airports. They should be used by any reader, interested in more detail and greater accuracy, to determine site-specific inversion heights. From the inversion height and from aircraft operations data, site-specific climbout and approach TIM's can be developed.

In airfields located in vicinities with a history of low stagnant inversions and air pollution episodes, it may be necessary to perform these calculations for several inversion heights characteristic of various seasons and times of day.

For military aircraft, times in mode will vary greatly between different aircraft type and mission. The variations usually occur for the idle mode because of different arming, queueing, startup, shutdown and taxi operational procedures. For example, the RF-4 (reconnaissance) does not require the F-4E (fighter) arming idle mode time. Special operational procedures can increase the standard LTO idle time by a factor of three. The result is higher carbon monoxide and hydrocarbon emissions (Ref. 38).

The assumption that an LTO cycle necessarily includes the five specified modes will not be correct at military aviation training bases, where a large fraction of all LTO's will be "touch and go" practice. Such operations involve no taxi/idle (in) or taxi/idle (out) modes. The maximum altitude reached may be only 500 to 1000 ft AGL for fixed wing aircraft and very much less for helicopter practice (Refs. 24 and 37). To calculate emissions during touch-and-go practice, the reader will require climbout and approach times appropriate to the training regimen. This information may be obtainable from base operations offices and training commands.

Total air carrier taxi-idle (ground-idle) times of 26 minutes are listed in Table 4-4. These are appropriate for congested metropolitan airports during periods of peak activity. These times will often be very much too high for airports at smaller cities and even for some at larger cities. When possible, the user should employ <u>observed</u> ground idle times.

In summary: TIM data reported herein should be used for guidance only in the absence of specific observations. The military data are not appropriate for primary training. The civil data refer to large, congested fields at times of heavy activity. All the data assume a 3000 ft AGL inversion height.

## 4.4 CALCULATIONS

If source data are expressed as exhaust concentrations, they can be converted to mass or modal emission rates only if gas volume, temperature, $CO_2$ concentration, etc., are known. Such calculations are described in detail in the U.S. Navy publication Aircraft Engine Emissions Catalog (Ref. 21). However, most of the source data for this report were modal emission rates (Table 4-3). These were converted to emission factors per LTO cycle by the following algorithm:

1. Locate the engine data in Table 5-2 and select for each of the five standard modes the appropriate power setting (e.g., "afterburner" for takeoff).
2. Using known service assignment and mission, select the appropriate TIM code (column) in Table 4-5.
3. For each mode, m, and pollutant, p, combine data of Tables 4-5 and 5-2:

$$\left(\frac{\Delta e}{\Delta t}\right)_{m,p} \cdot (TIM)_m \quad \text{lb/engine/mode}$$

4. Sum over all modes for each pollutant to produce

$$\sum_m (\Delta e/\Delta t)_{m,p} \cdot (TIM)_m \quad \text{lb/engine/LTO cycle}$$

5. Finally, calculate the emission factor per aircraft per LTO cycle by multiplying by the number of engines, N:

$$E_p = N \sum_m (\Delta e/\Delta t)_{m,p} \cdot (TIM)_m \quad \text{lb/LTO cycle for the aircraft}$$

This kind of calculation can be set up easily on a standard work sheet. With the aid of a hand calculator with one storage location, a conveniently designed work sheet permits the calculations for one aircraft to be completed in about five minutes (Fig. 4-1).

## 4.5 TIMES IN MODE AND ENGINE POWER SETTINGS

To perform the calculations outlined in Section 4.4, appropriate times in mode must be selected for the aircraft. In the absence of information specific to operation of a particular aircraft at a particular airfield, typical or average times in mode for sometimes broad categories of aircraft are used. Tables 4-4 and 4-5 present the TIM values used in this report.

The military data are in part averages extracted from a report by Naugle and Nelson (Ref. 32), who observed LTOs and interviewed pilots at

Aircraft _____ Engines: No. ____ Type _____ Model _____

Service Using: _____ Service Data Used _____ References _____

TIM Code

Does this check data from another source? Ref. _____

| MODE Mode Code | Power | TIM (min) | Emissions Per Engine | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | CO | | $NO_x$ | | THC | | $SO_x$ | | Particulate | |
| | | | lb/hr | lb | lb/hr | lb | lb/hr | lb | lb/hr | lb | lb/hr | lb |
| Taxi/Idle (Out) | | | | | | | | | | | | |
| Takeoff | | | | | | | | | | | | |
| Climbout | | | | | | | | | | | | |
| Approach | | | | | | | | | | | | |
| Taxi/Idle (In) | | | | | | | | | | | | |
| Total for One Engine | | | | lb | | lb | | lb | | lb | | lb |
| Total for Aircraft | | | | lb | | lb | | lb | | lb | | lb |
| (Emission Factor per LTO Cycle) | | | | kg | | kg | | kg | | kg | | kg |

Comments:

Figure 4-1. Sample work sheet for calculation of emission factor per LTO cycle.

TABLE 4-4. TYPICAL TIMES-IN-MODE FOR CIVIL LANDING-TAKEOFF CYCLES AT A LARGE CONJESTED METROPOLITAN AIRPORT (REFS. 2, 18, 19)

| Mode | Time-In-Mode (Minutes) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Air Carrier | | | | General Aviation | | | | Helicopter |
| | Jumbo Jet[a] | Long Range Jet[a] | Medium Range Jet[a] | Turboprop[b] | Piston Transport | Business Jet | Turboprop[b] | Piston[c] | |
| Taxi/Idle (Out) | 19.0 | 19.0 | 19.0 | 19.0 | 6.5 | 6.5 | 19.0 | 12.0 | 3.5 |
| Takeoff | 0.7 | 0.7 | 0.7 | 0.5 | 0.6 | 0.4 | 0.5 | 0.3 | — |
| Climbout | 2.2 | 2.2 | 2.2 | 2.5 | 5.0 | 0.5 | 2.5 | 4.98 | 6.5 |
| Approach | 4.0 | 4.0 | 4.0 | 4.5 | 4.6 | 1.6 | 4.5 | 6.0 | 6.5 |
| Taxi/Idle (In) | 7.0 | 7.0 | 7.0 | 7.0 | 6.5 | 6.5 | 7.0 | 4.0 | 3.5 |
| Total | 32.9 | 32.9 | 32.9 | 33.5 | 23.2 | 15.5 | 33.5 | 27.28 | 20.0 |

[a]Same times as EPA classes T2, T3, T4. See footnote a, Table 4-6.
[b]Same times as EPA classes T1 and P2. See footnote a, Table 4-6.
[c]Same times as EPA class P1. See footnote a, Table 4-6.

TABLE 4-5. TIMES-IN-MODE DURING MILITARY CYCLES (REFS. 21, 32).

| Mode | Time-in-Mode (Minutes) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Combat[a] | | Turbine Trainers | | | Turbine Transport[b] | | KC-135 & B-52 | Military Piston (All) | Military Helicopter (All) |
| | USAF | USN | USAF T37 & T38 | USAF Other | USN | USAF | USN[c] | | | |
| Code | 1 | 2 | 3 | 4 | 2 | 5 | 6 | 7 | 8 | 9 |
| Taxi/Idle (Out) | 18.5 | 6.5 | 12.8 | 6.8 | Same as Code 2 | 9.2 | 19.0 | 32.8 | 6.5 | 8.0 |
| Takeoff | 0.4 | 0.4 | 0.4 | 0.5 | | 0.4 | 0.5 | 0.7 | 0.6 | — |
| Climbout | 0.8 | 0.5 | 0.9 | 1.4 | | 1.2 | 2.5 | 1.6 | 5.0 | 6.8 |
| Approach | 3.5 | 1.6 | 3.8 | 4.0 | | 5.1 | 4.5 | 5.2 | 4.6 | 6.8 |
| Taxi/Idle (In) | 11.3 | 6.5 | 6.4 | 4.4 | | 6.7 | 7.0 | 14.9 | 6.5 | 7.0 |
| Total | 34.5 | 15.5 | 24.3 | 17.1 | | 22.6 | 33.5 | 55.2 | 23.2 | 28.6 |

[a] Includes fighters and attack aircraft only.

[b] Includes transport, cargo, observation, patrol, antisubmarine, early warning, and utility; i.e., all turbine aircraft not specifically listed in other columns.

[c] Same time as EPA civil class P2. Cf. footnote, Table 4-6.

five airfields (Nellis, Kelly, Randolph, Wright-Patterson, and Travis) to determine TIMs for nine modes for each major USAF aircraft type. Long idle times for two trainers presumably reflect the complexity of the training regimen, rather than operating characteristics of the engines. Long ground times for the KC-135 and B-52 were said to originate in long check outs for electronic instrumentation.

Modal emission rate data for civil aircraft engines (Table 5-1) are reported conveniently for idle, takeoff climbout, and approach. Both taxi/idle (in) and taxi/idle (out) modes would require "idle" data.

However, varying military mission operating requirements and lack of standards for reporting format have caused military engine modal emission rates for some individual engines to be reported at as many as fourteen power settings. USAF and Navy nomenclature and practices differ. These facts have combined to make the selection of power settings for which to report emissions herein rather less systematic and more cumbersome than for civil aircraft.

As a guide to current practice, Tables 4-6 and 4-7 present standard power settings. Table 4-6 is for information only, as it was not needed to select civil data in this report. Table 4-7, however, was essential, and can be used by the reader who wishes to recalculate table entries for another selection of engine data.

## 4.6 SUPERSONIC TRANSPORT (SST) AIRCRAFT

The BAC/Aerospatiale Concorde is the only "SST" now in service. In the U.S., it lands only at Dulles, Kennedy, and Dallas-Ft. Worth. Nevertheless, its emission characteristics have elicited sufficient public comment to justify its inclusion in this report.

The Concorde has a 6-mode LTO cycle rather than the 5-mode cycle used for all other fixed wing aircraft reported herein. Its TIM and engine power settings are given in Tables 4-8 and 4-9.

TABLE 4-6. ENGINE POWER SETTINGS FOR THE STANDARD EPA LTO CYCLE FOR COMMERCIAL ENGINES (REF. 21)

| Mode | Power Setting (percent thrust or horsepower) | | | |
|---|---|---|---|---|
| | Class T1, P2[a] | Class T2, T3, T4[a] | Class P1[a] | Helicopter |
| Taxi/Idle (out) | Idle | Idle | Idle | |
| Takeoff | 100% | 100% | 100% | |
| Climbout | 90% | 85% | 75%-100% | Undefined |
| Approach | 30% | 30% | 40% | |
| Taxi/Idle (in) | Idle | Idle | Idle | |

[a]As defined by EPA (Refs. 18. 19).

"Class T1" means all aircraft turbofan or turbojet engines except engines of Class T5 of rated power less than 8,000 pounds thrust.

"Class T2" means all turbofan or turbojet aircraft engines except engines of Class T3, T4, and T5 of rated power of 8,000 pounds thrust or greater.

"Class T3" means all aircraft gas turbine engines of the JT3D model family.

"Class T4" means all aircraft gas turbine engines of the JT8D model family.

"Class P1" means all aircraft piston engines, except radial engines.

"Class P2" means all aircraft turboprop engines.

TABLE 4-7. ENGINE POWER SETTINGS FOR A TYPICAL MILITARY CYCLE (REF. 21)

| Mode | Power Setting (percent thrust or horsepower) | | | |
|---|---|---|---|---|
| | Military Transport | Military Jet | Military Piston | Military Helicopter |
| Taxi/Idle (out) | Idle | Idle | 5-10% | Idle |
| Takeoff | Military | Military or Afterburner | 100% | — |
| Climbout | 90-100% | Military | 75% | 60-75% |
| Approach | 30% | 84-86% | 30% | 45-50% |
| Taxi/Idle (in) | Idle | Idle | 5-10% | Idle |

TABLE 4-8. TIMES-IN-MODE FOR CIVIL SUPERSONIC TRANSPORTS (SSTs) (REF. 20)

| Mode | SST Time-In-Mode (min.)[a] |
|---|---|
| Taxi/Idle (Out) | 19.0 |
| Takeoff | 1.2 |
| Climbout | 2.0 |
| Descent | 1.2 |
| Approach | 2.3 |
| Taxi/Idle (In) | 7.0 |

[a]Same times as EPA class T5; see footnote, Table 4-9.

TABLE 4-9. ENGINE POWER SETTINGS FOR CIVIL SUPERSONIC TRANSPORTS (SSTs) (REF. 20)

| Mode | SST Engine Power (EPA Class T5)[a] |
|---|---|
| Taxi/Idle (Out) | Idle |
| Takeoff | 100% |
| Climbout | 65% |
| Descent | 15% |
| Approach | 34% |
| Taxi/Idle (In) | Idle |

[a]"Class T5" means all aircraft gas turbine engines employed for propulsion of aircraft designed to operate at supersonic flight speeds.

# 5. MODAL EMISSION RATES

## 5.1 CIVIL DATA

The numerical civil data reported in Table 5-1 are reported by USEPA Office of Mobile Source Air Pollution Control (Ref. 2) except for format changes and the addition of $SO_x$ data and particulates data. $SO_x$ emissions are worst case values calculated by material balance, as explained in footnote d. The particulates data are quite old.

## 5.2 MILITARY DATA

Military data were collected from a variety of sources (references appear in Table 5-2), and in many instances had to be processed for presentation here. Frequently the data were expressed as mass emission rates, 1000 $\Delta e/\Delta F$, ("emission indices"), which are related to modal emission rates, $\Delta e/\Delta t$, as follows:

$$\frac{\Delta e}{\Delta t} = 10^{-3} \frac{\Delta F}{\Delta t} \left(1000 \frac{\Delta e}{\Delta F}\right)$$

where $\Delta F/\Delta t$ is the fuel rate, and all quantities refer to a specified mode, at specified engine power setting.

Sulfur oxides were calculated by material balance, the method being explained in footnote c of Table 5-2.

As for the civil compilation, particulates data are scarce, and some are old. Occasionally SAE smoke numbers were reported, and sometimes % opacity. One researcher used Ringelmann numbers. None of these are currently suitable for conversion to mass quantities usable in this report. As for gaseous pollutants, concentrations cannot be converted to mass/unit time without supporting information such as volumes, temperature, pressure, $CO_2$ concentration, etc.

Quantitative information related to the accuracy of these data is not often available. However, the U.S. Navy compilation (Ref. 21) includes numerous examples of replicate experiments which permit precision to be estimated. Although beyond the scope of the present work, an analysis of the Navy replicate data would be a useful exercise. Generally, agreeement within ±10% (often very much better) is reported. This is remarkable, since aircraft engine emissions measurements must be among the most difficult source tests performed.

TABLE 5-1. MODAL EMISSION RATES – CIVIL AIRCRAFT ENGINES (REFS. 2, 20)

| Model-Series Mfg.[a] Type[a] | Mode | Fuel Rate | | CO | | $NO_x$[b] | | Total HC[c] | | $SO_x$[d] | | Solid Particulates[e] | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | lb/hr | kg/hr | lb/hr | kg/hr | lb/hr | kg/hr | lb/hr | kg/hr | lb/hr | kg/hr | lb/hr | kg/hr |
| 250B17B | Idle | 63 | 28.58 | 6.13 | 2.76 | 0.09 | 0.041 | 1.27 | 0.576 | 0.06 | 0.03 | | |
| All. TP | Takeoff | 265 | 120.2 | 2.07 | 0.939 | 1.75 | 0.794 | 0.07 | 0.032 | 0.27 | 0.12 | | |
| | Climbout | 245 | 111.1 | 2.21 | 1.00 | 1.46 | 0.662 | 0.09 | 0.041 | 0.25 | 0.11 | | |
| | Approach | 85 | 38.56 | 4.13 | 1.87 | 0.19 | 0.086 | 0.44 | 0.200 | 0.09 | 0.04 | | |
| 501D22A | Idle | 610 | 276.7 | 26.60 | 12.07 | 2.15 | 0.975 | 10.74 | 4.87 | 0.61 | 0.28 | | |
| All. TP | Takeoff | 2376 | 1078 | 4.85 | 2.20 | 21.10 | 9.57 | 0.67 | 0.304 | 2.38 | 1.08 | | |
| | Climbout | 2198 | 997 | 4.53 | 2.05 | 20.27 | 9.19 | 1.96 | 0.889 | 2.20 | 1.00 | | |
| | Approach | 1140 | 517.1 | 5.81 | 2.64 | 8.54 | 3.87 | 2.23 | 1.01 | 1.14 | 0.52 | | |
| TPE 331-3 | Idle | 112.0 | 50.8 | 6.89 | 3.12 | 0.320 | 0.145 | 8.86 | 4.02 | 0.11 | 0.05 | 0.3[f] | 0.14[f] |
| GA TP | Takeoff | 458.0 | 207.7 | 0.350 | 0.159 | 5.66 | 2.57 | 0.050 | 0.023 | 0.46 | 0.21 | 0.8 | 0.36 |
| | Climbout | 409.0 | 185.5 | 0.400 | 0.181 | 4.85 | 2.20 | 0.060 | 0.027 | 0.41 | 0.19 | 0.6 | 0.27 |
| | Approach | 250.0 | 113.4 | 1.74 | 0.789 | 2.48 | 1.12 | 0.160 | 0.073 | 0.25 | 0.11 | 0.6 | 0.27 |
| TPE331-2 | Idle | 105.0 | 47.6 | 6.73 | 3.05 | 0.27 | 0.22 | 9.58 | 4.34 | 0.11 | 0.05 | (Assume 331-3 | |
| GA TP | Takeoff | 405.0 | 183.7 | 0.38 | 0.172 | 4.14 | 1.88 | 0.16 | 0.072 | 0.41 | 0.18 | data) | |
| | Climbout | 372.0 | 168.7 | 0.51 | 0.231 | 3.69 | 1.67 | 0.15 | 0.068 | 0.37 | 0.17 | | |
| | Approach | 220.0 | 99.8 | 3.65 | 1.66 | 1.82 | 0.826 | 0.59 | 0.268 | 0.22 | 0.10 | | |
| TPE 731-2 | Idle | 181.0 | 82.1 | 11.11 | 5.04 | 0.54 | 0.245 | 4.05 | 1.84 | 0.18 | 0.08 | | |
| GA TF | Takeoff | 1552.0 | 704.0 | 1.86 | 0.844 | 29.8 | 13.52 | 0.14 | 0.064 | 1.55 | 0.70 | | |
| | Climbout | 1385.0 | 628.2 | 1.80 | 0.816 | 23.68 | 10.74 | 0.12 | 0.054 | 1.39 | 0.63 | | |
| | Approach | 521.0 | 236.3 | 9.53 | 4.32 | 3.59 | 1.63 | 1.51 | 0.685 | 0.52 | 0.24 | | |
| CJ 610-2C | Idle | 510.0 | 231.3 | 79.05 | 35.86 | 0.46 | 0.209 | 9.18 | 4.16 | 0.51 | 0.23 | | |
| GE TJ | Takeoff | 2780.0 | 1261.0 | 75.06 | 34.05 | 11.68 | 5.30 | 0.28 | 0.127 | 2.78 | 1.26 | | |
| | Climbout | 2430.0 | 1102.0 | 65.61 | 29.76 | 8.99 | 4.08 | 0.49 | 0.222 | 2.43 | 1.10 | | |
| | Approach | 1025.0 | 464.9 | 90.20 | 40.91 | 1.54 | 0.698 | 2.77 | 1.26 | 1.03 | 0.46 | | |
| CF700-2D | Idle | 460 | 208.7 | 71.30 | 32.34 | 0.41 | 0.186 | 8.28 | 3.76 | 0.46 | 0.21 | | |
| GE TF | Takeoff | 2607 | 1182 | 57.35 | 26.01 | 14.60 | 6.62 | 0.26 | 0.118 | 2.61 | 1.18 | | |
| | Climbout | 2322 | 1053 | 58.05 | 26.33 | 9.98 | 4.53 | 0.23 | 0.104 | 2.32 | 1.05 | | |
| | Approach | 919 | 416.9 | 56.98 | 25.85 | 1.65 | 0.748 | 1.29 | 0.585 | 0.92 | 0.42 | | |
| CF6-6D | Idle | 1063 | 482.2 | 65.06 | 29.51 | 4.88 | 2.21 | 21.79 | 9.88 | 1.06 | 0.48 | 0.04[f] | 0.02[f] |
| GE TF | Takeoff | 13750 | 6237 | 8.25 | 3.74 | 467.5 | 212.1 | 8.25 | 3.74 | 13.75 | 6.24 | 0.54 | 0.24 |
| | Climbout | 11329 | 5139 | 6.80 | 3.03 | 309.2 | 140.2 | 6.80 | 3.08 | 11.33 | 5.14 | 0.54 | 0.24 |
| | Approach | 3864 | 1753 | 23.18 | 10.51 | 41.54 | 18.84 | 6.96 | 3.16 | 3.86 | 1.75 | 0.44 | 0.20 |
| CF6-50C | Idle | 1206 | 547 | 88.04 | 39.93 | 3.02 | 1.37 | 36.18 | 16.41 | 1.21 | 0.55 | (Assume CF6-6D | |
| GE TF | Takeoff | 18900 | 8573 | 0.38 | 0.172 | 670.95 | 304.3 | 0.19 | 0.086 | 18.90 | 8.57 | data) | |
| | Climbout | 15622 | 7104 | 4.70 | 2.13 | 462.0 | 209.6 | 0.16 | 0.073 | 15.62 | 7.10 | | |
| | Approach | 5280 | 2395 | 22.70 | 10.30 | 52.8 | 23.95 | 0.05 | 0.023 | 5.28 | 2.40 | | |

TABLE 5-1 (CONTINUED)

| Model-Series Mfg.[a] Type[a] | Mode | Fuel Rate | | CO | | $NO_x$[b] | | Total HC[c] | | $SO_x$[d] | | Solid Particulates[e] | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | lb/hr | kg/hr | lb/hr | kg/hr | lb/hr | kg/hr | lb/hr | kg/hr | lb/hr | kg/hr | lb/hr | kg/hr |
| JT3D-7 | Idle | 1013 | 459.5 | 140.8 | 63.87 | 2.23 | 1.01 | 124.6 | 56.52 | 1.01 | 0.46 | 0.45[f] | 0.20[f] |
| P&W TF | Takeoff | 9956 | 4516 | 8.96 | 4.06 | 126.4 | 57.34 | 4.98 | 2.26 | 9.96 | 4.52 | 8.25 | 3.7 |
| | Climbout | 8188 | 3714 | 15.56 | 7.06 | 78.6 | 35.65 | 3.28 | 1.49 | 8.19 | 3.71 | 8.5 | 3.9 |
| | Approach | 3084 | 1399 | 60.14 | 27.28 | 16.35 | 7.42 | 6.48 | 2.94 | 3.08 | 1.40 | 8.0 | 3.6 |
| JT8D-17 | Idle | 1150 | 521.6 | 39.10 | 17.74 | 3.91 | 1.77 | 10.10 | 4.58 | 1.15 | 0.52 | 0.36[f,g] | 0.16[f,g] |
| P&W TF | Takeoff | 9980 | 4527 | 6.99 | 3.17 | 202.6 | 91.90 | .50 | 0.227 | 9.98 | 4.53 | 3.7 | 1.7 |
| | Climbout | 7910 | 3588 | 7.91 | 3.59 | 123.4 | 55.97 | .40 | 0.181 | 7.91 | 3.59 | 2.6 | 1.2 |
| | Approach | 2810 | 1275 | 20.23 | 9.18 | 19.39 | 8.80 | 1.41 | 0.640 | 2.81 | 1.28 | 1.5 | 0.68 |
| JT9D-7 | Idle | 1849 | 838.7 | 142.4 | 64.59 | 5.73 | 2.60 | 55.10 | 24.99 | 1.85 | 0.84 | 2.2[f] | 1.0 |
| P&W TF | Takeoff | 16142 | 7322 | 3.23 | 1.47 | 474.6 | 215.3 | 0.81 | 0.367 | 16.14 | 7.32 | 3.75 | 1.7 |
| | Climbout | 13193 | 5984 | 6.60 | 2.99 | 282.3 | 128.0 | 1.32 | 0.599 | 13.19 | 5.98 | 4.0 | 1.8 |
| | Approach | 4648 | 2108 | 44.62 | 20.24 | 36.25 | 16.44 | 4.65 | 2.11 | 4.65 | 2.11 | 2.3 | 1.0 |
| JT9D-70 | Idle | 1800 | 816.5 | 61.20 | 27.76 | 5.76 | 2.61 | 12.24 | 0.55 | 1.80 | 0.82 | | |
| P&W TF | Takeoff | 19380 | 8791 | 3.88 | 1.76 | 600.8 | 272.5 | 2.91 | 1.32 | 19.38 | 8.79 | (assume JT9D-7 data) | |
| | Climbout | 15980 | 7248 | 4.79 | 2.17 | 386.7 | 175.4 | 2.40 | 1.09 | 15.98 | 7.25 | | |
| | Approach | 5850 | 2654 | 7.61 | 3.45 | 47.39 | 21.50 | 2.63 | 1.19 | 5.85 | 2.65 | | |
| JT15D-1 | Idle | 215 | 97.52 | 19.46 | 8.83 | 0.54 | 0.245 | 7.48 | 3.39 | 0.22 | 0.10 | | |
| PWC TF | Takeoff | 1405 | 637.3 | 1.41 | 0.640 | 14.19 | 6.44 | 0 | 0 | 1.41 | 0.64 | | |
| | Climbout | 1247 | 565.6 | 1.25 | 0.567 | 11.35 | 5.15 | 0 | 0 | 1.25 | 0.57 | | |
| | Approach | 481 | 218.2 | 11.45 | 5.19 | 2.45 | 1.11 | 1.59 | 0.721 | 0.48 | 0.22 | | |
| PT6A-27 | Idle | 115 | 52.16 | 7.36 | 3.34 | 0.28 | 0.127 | 5.77 | 2.62 | 0.12 | 0.05 | | |
| PWC TP | Takeoff | 425 | 192.8 | 0.43 | 0.195 | 3.32 | 1.51 | 0 | 0 | 0.43 | 0.19 | | |
| | Climbout | 400 | 181.4 | 0.48 | 0.218 | 2.80 | 1.27 | 0 | 0 | 0.40 | 0.18 | | |
| | Approach | 215 | 97.52 | 4.95 | 2.24 | 1.80 | 0.816 | 0.47 | 0.213 | 0.22 | 0.10 | | |
| PT6A-41 | Idle | 147 | 66.63 | 16.95 | 7.69 | 0.29 | 0.132 | 14.94 | 6.78 | 0.15 | 0.07 | | |
| PWC TP | Takeoff | 510 | 231.3 | 2.60 | 1.18 | 4.07 | 1.85 | 0.89 | 0.404 | 0.51 | 0.23 | | |
| | Climbout | 473 | 214.6 | 3.07 | 1.39 | 3.58 | 1.62 | 0.96 | 0.435 | 0.47 | 0.21 | | |
| | Approach | 273 | 123.8 | 9.50 | 4.31 | 1.27 | 0.576 | 6.20 | 2.81 | 0.27 | 0.12 | | |
| Spey 555-15[h] | Idle | 915 | 415 | 83.2 | 37.7 | 1.6 | 0.7 | 86.0 | 43.5 | 0.92 | 0.42 | | |
| RR TF | Takeoff | 5734 | 2600 | 6.5 | 3.0 | 109.2 | 49.5 | 29.5 | 13.4 | 5.73 | 2.60 | | |
| | Climbout | 4677 | 2121 | 0.0 | 0.0 | 68.7 | 31.2 | 2.5 | 1.1 | 4.68 | 2.12 | | |
| | Approach | 1744 | 791 | 34.8 | 15.8 | 10.2 | 4.6 | 14.3 | 6.5 | 1.74 | 0.79 | | |
| Spey MK 511f[h] | Idle | 946 | 429.1 | 104.4 | 47.36 | 0.785 | 0.356 | 80.03 | 36.30 | 0.95 | 0.43 | 0.17 | 0.077 |
| RR TF | Takeoff | 7057 | 3201 | 16.16 | 7.33 | 156.7 | 71.08 | 13.97 | 6.34 | 7.06 | 3.20 | 16.0 | 7.3 |
| | Climbout | 5752 | 2609 | 0.0 | 0.0 | 116.8 | 52.98 | 0.0 | 0.0 | 5.75 | 2.61 | 10.0 | 4.5 |
| | Approach | 2204 | 999.7 | 48.71 | 22.09 | 16.00 | 7.26 | 20.56 | 9.33 | 2.20 | 1.00 | 1.5 | 0.68 |
| M45H-01[h] | Idle | 366 | 166.0 | 55.63 | 25.23 | 0.622 | 0.282 | 11.53 | 5.23 | 0.37 | 0.17 | | |
| RR (Bristol) | Takeoff | 3590 | 1628 | 7.18 | 3.26 | 32.31 | 14.66 | 0.718 | 0.326 | 3.59 | 1.62 | | |
| TF | Climbout | 3160 | 1433 | 9.48 | 4.30 | 25.28 | 11.47 | 0.632 | 0.287 | 3.16 | 1.43 | | |
| | Approach | 1067 | 484.0 | 53.56 | 24.29 | 3.57 | 1.62 | 6.61 | 3.00 | 1.07 | 0.48 | | |

TABLE 5-1 (CONTINUED)

| Model-Series Mfg.[a] Type[a] | Mode | Fuel Rate lb/hr | Fuel Rate kg/hr | CO lb/hr | CO kg/hr | $NO_x$[b] lb/hr | $NO_x$[b] kg/hr | Total HC[c] lb/hr | Total HC[c] kg/hr | $SO_x$[d] lb/hr | $SO_x$[d] kg/hr | Solid Particulates[e] lb/hr | Solid Particulates[e] kg/hr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RB-211-22B[h] RR TF | Idle | 1718 | 779.3 | 137.6 | 64.42 | 5.31 | 2.41 | 100.1 | 45.36 | 1.72 | 0.78 | | |
| | Takeoff | 14791 | 6709 | 5.62 | 2.55 | 504.1 | 228.7 | 29.14 | 13.22 | 14.79 | 6.71 | | |
| | Climbout | 12205 | 5536 | 14.89 | 6.75 | 301.9 | 136.9 | 8.30 | 3.76 | 12.21 | 5.54 | | |
| | Approach | 4376 | 1985 | 93.78 | 42.54 | 32.26 | 14.63 | 32.16 | 14.59 | 4.38 | 1.99 | | |
| RB-211-524[h] RR TF | Idle | 1769 | 802.4 | 35.91 | 16.29 | 4.74 | 2.15 | 5.43 | 2.46 | 1.77 | 0.80 | | |
| | Takeoff | 17849 | 8096 | 7.32 | 3.32 | 660.4 | 299.6 | 1.96 | 0.889 | 17.85 | 8.10 | | |
| | Climbout | 14688 | 6662 | 7.34 | 3.33 | 470.0 | 213.2 | 2.50 | 1.13 | 14.69 | 6.67 | | |
| | Approach | 5450 | 2472 | 11.72 | 5.32 | 62.89 | 28.53 | 0.545 | 0.247 | 5.45 | 2.47 | | |
| RB-401-06 RR TF | Idle | 330 | 149.7 | 10.07 | 4.57 | 0.825 | 0.374 | 0.924 | 0.419 | 0.33 | 0.15 | | |
| | Takeoff | 2400 | 1089 | 2.40 | 1.09 | 30.0 | 13.61 | 0.120 | 0.054 | 2.40 | 1.09 | | |
| | Climbout | 2130 | 966.2 | 2.77 | 1.26 | 24.07 | 10.92 | 0.107 | 0.049 | 2.13 | 0.97 | | |
| | Approach | 775 | 351.5 | 5.04 | 2.29 | 3.88 | 1.76 | 0.155 | 0.070 | 0.78 | 0.35 | | |
| Dart RDa7 RR TP | Idle | 411 | 186.4 | 37.61 | 17.06 | 0.292 | 0.132 | 25.52 | 11.58 | 0.41 | 0.19 | | |
| | Takeoff | 1409 | 639.1 | 4.79 | 2.17 | 8.51 | 3.86 | 8.75 | 3.97 | 1.41 | 0.64 | | |
| | Climbout | 1248 | 566.1 | 4.26 | 1.93 | 5.55 | 2.52 | 2.15 | 0.975 | 1.25 | 0.57 | | |
| | Approach | 645 | 292.6 | 21.48 | 9.74 | 0.568 | 0.258 | 0.0 | 0.0 | 0.65 | 0.29 | | |
| Tyne[i] RR TP | Idle | 619 | 280.8 | 40.79 | 18.50 | 0.477 | 0.216 | 6.63 | 3.01 | 0.62 | 0.28 | | |
| | Takeoff | 2372 | 1076 | 1.21 | 0.549 | 27.11 | 12.30 | 2.87 | 1.31 | 2.37 | 1.08 | | |
| | Climbout | 2188 | 922.5 | 1.29 | 0.585 | 25.23 | 11.44 | 2.63 | 1.19 | 2.19 | 0.99 | | |
| | Approach | 1095 | 496.7 | 11.30 | 5.13 | 9.00 | 4.08 | 2.68 | 1.22 | 1.10 | 0.50 | | |
| Olympus 593 MK610[h, i] RR (Bristol) TJ | Idle | 3060 | 1388 | 342.7 | 155.4 | 9.72 | 4.41 | 119.3 | 54.11 | 3.06 | 1.39 | | |
| | Takeoff | 52200 | 23673 | 1513.8 | 686.5 | 542.9 | 246.2 | 151.4 | 68.7 | 52.2 | 23.7 | | |
| | Climbout | 19700 | 8936 | 275.8 | 125.1 | 169.4 | 76.84 | 31.52 | 14.30 | 19.70 | 8.94 | | |
| | Descent | 5400 | 2449 | 426.6 | 193.5 | 18.9 | 8.6 | 132.3 | 60.0 | 5.4 | 2.4 | | |
| | Approach | 9821 | 4455 | 451.8 | 204.9 | 41.25 | 18.71 | 93.30 | 42.32 | 9.82 | 4.46 | | |
| O-200 Con. O | Idle | 8.24 | 3.75 | 5.31 | 2.42 | 0.013 | 0.006 | 0.239 | 0.107 | 0.0 | 0 | | |
| | Takeoff | 45.17 | 20.53 | 44.0 | 20.0 | 0.220 | 0.100 | 0.940 | 0.427 | 0.01 | 0 | | |
| | Climbout | 45.17 | 20.53 | 44.0 | 20.0 | 0.220 | 0.100 | 0.940 | 0.427 | 0.01 | 0 | | |
| | Approach | 25.50 | 11.59 | 30.29 | 13.75 | 0.029 | 0.013 | 0.847 | 0.385 | 0.01 | 0 | | |
| TSIO-360C Con. O | Idle | 11.5 | 5.21 | 6.81 | 3.09 | 0.022 | 0.009 | 1.59 | 0.723 | 0.0 | 0.0 | | |
| | Takeoff | 133. | 60.3 | 143.9 | 65.3 | 0.36 | 0.16 | 1.22 | 0.55 | 0.03 | 0.01 | | |
| | Climbout | 99.5 | 45.1 | 95.6 | 43.4 | 0.43 | 0.20 | 0.95 | 0.43 | 0.02 | 0.01 | | |
| | Approach | 61.0 | 27.7 | 60.7 | 27.5 | 0.23 | 0.10 | 0.69 | 0.31 | 0.01 | 0.01 | | |
| 6-285-B (Tiara) Con. O | Idle | 72.12 | 10.03 | 26.23 | 11.90 | 0.0334 | 0.0152 | 0.773 | 0.350 | 0.0 | 0.0 | | |
| | Takeoff | 153.0 | 69.39 | 152.7 | 69.3 | 0.899 | 0.408 | 1.78 | 0.806 | 0.03 | 0.01 | | |
| | Climbout | 166.0 | 52.61 | 110.9 | 50.3 | 0.913 | 0.414 | 1.39 | 0.632 | 0.02 | 0.01 | | |
| | Approach | 83.5 | 37.88 | 85.39 | 38.77 | 0.394 | 0.179 | 1.343 | 0.609 | 0.02 | 0.01 | | |

TABLE 5-1 (CONCLUDED)

| Model-Series Mfg.[a] Type[a] | Mode | Fuel Rate lb/hr | Fuel Rate kg/hr | CO lb/hr | CO kg/hr | $NO_x$[b] lb/hr | $NO_x$[b] kg/hr | Total HC[c] lb/hr | Total HC[c] kg/hr | $SO_x$[d] lb/hr | $SO_x$[d] kg/hr | Solid Particulate[e] lb/hr | Solid Particulate[e] kg/hr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| O-320 | Idle | 9.48 | 4.30 | 10.21 | 4.63 | 0.0049 | 0.0022 | 0.350 | 0.159 | 0.0 | 0.0 | | |
| Lyc. O | Takeoff | 89.1 | 40.4 | 96.0 | 43.5 | 0.195 | 0.088 | 1.05 | 0.475 | 0.02 | 0.01 | | |
| | Climbout | 66.7 | 30.3 | 66.0 | 29.9 | 0.265 | 0.120 | 0.826 | 0.375 | 0.01 | 0.01 | | |
| | Approach | 46.5 | 21.1 | 56.8 | 25.8 | 0.044 | 0.020 | 0.895 | 0.406 | 0.01 | 0.0 | | |
| IO-320-DIAD | Idle | 7.84 | 3.56 | 4.86 | 2.20 | 0.009 | 0.0041 | 0.283 | 0.128 | 0.0 | 0.0 | | |
| Lyc. O | Takeoff | 91.67 | 41.57 | 109.3 | 49.55 | 0.167 | 0.0756 | 1.047 | 0.475 | 0.02 | 0.01 | | |
| | Climbout | 61.42 | 27.85 | 54.55 | 24.74 | 0.344 | 0.156 | 0.588 | 0.267 | 0.01 | 0.01 | | |
| | Approach | 37.67 | 17.08 | 35.57 | 16.13 | 0.128 | 0.058 | 0.460 | 0.208 | 0.01 | 0.0 | | |
| IO-360-B | Idle | 8.09 | 3.68 | 7.26 | 3.29 | 0.0094 | 0.0042 | 0.398 | 0.180 | 0.0 | 0.0 | | |
| Lyc. O | Takeoff | 103.0 | 46.7 | 123.5 | 56.0 | 0.205 | 0.093 | 1.03 | 0.469 | 0.02 | 0.01 | | |
| | Climbout | 71.7 | 32.5 | 70.5 | 32.0 | 0.329 | 0.149 | 0.585 | 0.265 | 0.01 | 0.01 | | |
| | Approach | 36.6 | 16.6 | 25.3 | 11.5 | 0.372 | 0.169 | 0.355 | 0.161 | 0.01 | 0.0 | | |
| TIO-540- | Idle | 25.06 | 11.36 | 32.42 | 14.70 | 0.0097 | 0.0044 | 1.706 | 0.774 | 0.01 | 0.0 | | |
| J2B2 | Takeoff | 259.7 | 117.8 | 374.5 | 169.8 | 0.094 | 0.043 | 3.21 | 1.46 | 0.05 | 0.02 | | |
| Lyc. O | Climbout | 204.5 | 92.7 | 300.8 | 136.4 | 0.0481 | 0.0218 | 3.40 | 1.54 | 0.04 | 0.02 | | |
| | Approach | 99.4 | 45.1 | 125.4 | 56.9 | 0.138 | 0.0623 | 1.33 | 0.604 | 0.02 | 0.01 | | |

[a] Abbreviations: All – Detroit Diesel Allison Division of General Motors; Con – Teledyne/Continental; GA – Garrett AiResearch; GE – General Electric; Lyc – Avco/Lycoming; P&W – Pratt & Whitney; PWC – Pratt & Whitney Aircraft of Canada; RR – Rolls Royce; TJ – Turbojet; TF – Turbofan ("fanjet"); TP – Turboprop; O – Reciprocating (Piston) Opposed.

[b] Nitrogen oxides reported as $NO_2$.

[c] Total hydrocarbons. Includes unburned hydrocarbons and organic pyrolysis products.

[d] Sulfur oxides and sulfuric acid reported as $SO_2$. Calculated from fuel rate and 0.05 wt% sulfur in Jet A and Jet B fuel, or 0.01 wt% sulfur in aviation gasoline. For turbine engines, the conversion is therefore $SO_x$ (lb/hr) = $10^{-3}$ (fuel rate), and for piston engines, the conversion is $SO_x$ (lb/hr) = $2 \times 10^{-4}$ (fuel rate).

[e] All particulate data are from Ref. 39.

[f] The indicated reference does not specify series number for this model engine.

[g] "Diluted smokeless" JT 8D. Note: JT8D is a turbofan engine and is not equivalent to the JT8 (Military J52) turbojet engine.

[h] All Rolls Royce data are based upon an arbitrary 7% idle which does not reflect the actual situation. In reality, Rolls Royce engines will idle at 5-6% with correspondingly higher emissions (Ref. 20).

[i] See discussion of SST LTO-cycle, Section 4.6.

TABLE 5-2. MODAL EMISSION RATES – MILITARY AIRCRAFT ENGINES

| Turbojet Model-Series (Civil Version) Mfg. Type[g] | Mode | Fuel Rate | | CO | | $NO_x$[a] | | Total HC[b] | | $SO_x$[c] | | Particulates[d, e] | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | lb/hr | kg/hr | lb/hr | kg/hr | lb/hr | kg/hr | lb/hr | kg/hr | lb/hr | kg/hr | lb/hr | kg/hr |
| J 52-P-6B (JT8) P&W TJ (Ref. 21) | Idle | 778 | 353 | 95.8 | 43.5 | 1.5 | 0.7 | 12.5 | 5.7 | 0.8 | 0.4 | | |
| | 75% (rpm) | 1646 | 747 | 59.2 | 26.9 | 5.9 | 2.7 | 6.3 | 2.9 | 1.6 | 0.7 | | |
| | 85% (rpm) | 2894 | 1313 | 53.0 | 24.0 | 15.2 | 6.9 | 2.4 | 1.1 | 2.9 | 1.3 | | |
| | 90% (rpm) | 3991 | 1810 | 43.4 | 19.7 | 25.9 | 11.7 | 0.9 | 0.4 | 4.0 | 1.8 | | |
| | Intermed. (MIL) | 6985 | 3168 | 30.7 | 13.9 | 66.0 | 29.9 | 0.0 | 0.0 | 7.0 | 3.2 | | |
| J57-P-22 (JT3C) P&W TJ (Refs. 21, 32) | Idle | 1087 | 493 | 64.4 | 29.2 | 2.7 | 1.2 | 55.8 | 25.3 | 1.1 | 0.5 | 8.3 | 3.8 |
| | 75% (rpm) | 1693 | 768 | 39.8 | 18.1 | 5.0 | 2.3 | 21.0 | 9.5 | 1.7 | 0.8 | | |
| | 75% (Thrust) | 4885 | 2216 | 33.1 | 15.0 | 34.4 | 15.6 | 9.2 | 4.2 | 4.9 | 2.2 | | |
| | Normal Rated | 6788 | 3079 | 22.4 | 10.2 | 61.6 | 27.9 | 6.6 | 3.0 | 6.8 | 3.1 | | |
| | Intermed. (MIL) | 8358 | 3791 | 14.9 | 6.8 | 93.3 | 42.3 | 5.4 | 2.4 | 8.4 | 3.8 | 12.0 | 5.4 |
| | Afterburner | 35851 | 16262 | 1156.0 | 524.4 | 152.8 | 69.3 | 16.7 | 7.6 | 35.9 | 16.3 | | |
| J65-W-20 Wr. TJ (Ref. 21) | Idle | 1333 | 605 | 66.9 | 30.3 | 3.7 | 1.7 | 5.0 | 2.3 | 1.3 | 0.6 | | |
| | 75% (rpm) | 2346 | 1064 | 51.2 | 23.2 | 11.3 | 5.1 | 3.2 | 1.5 | 2.3 | 1.0 | | |
| | 85% (rpm) | 3260 | 1479 | 52.6 | 23.9 | 23.7 | 10.8 | 0.9 | 0.4 | 3.3 | 1.5 | | |
| | 90% (rpm) | 3951 | 1629 | 56.5 | 25.6 | 31.5 | 14.3 | 0.5 | 0.2 | 4.0 | 1.8 | | |
| | Intermed. (MIL) | 6421 | 2913 | 49.6 | 22.5 | 48.5 | 22.0 | 0.2 | 0.1 | 6.4 | 2.9 | | |
| J69-T-25 Con. TJ (Ref. 32) | Idle | 453 | 205 | 48.2 | 21.9 | 1.5 | 0.7 | 3.6 | 1.6 | 0.4 | 0.2 | | |
| | Approach (53% Thrust) | 1052 | 477 | 50.0 | 22.7 | 5.5 | 2.5 | 0.04 | 0.02 | 1.1 | 0.5 | | |
| | Military | 1907 | 865 | 39.3 | 17.8 | 13.2 | 6.0 | 0.04 | 0.02 | 1.9 | 0.9 | | |
| J75-P-17 P&W TJ (Ref. 32) | Idle | 1700 | 771 | 129.5 | 58.7 | 2.2 | 1.0 | 96.7 | 43.9 | 1.7 | 0.8 | 0.8 | 0.4 |
| | Normal Cruise, Approach (90% Thrust) | 11300 | 5126 | 15.8 | 7.2 | 134.5 | 61.0 | 1.1 | 0.5 | 11.3 | 5.1 | 1.1 | 0.5 |
| | Military | 13200 | 5988 | 7.9 | 3.6 | 108.2 | 49.1 | 3.0 | 1.4 | 13.2 | 6.0 | 13.9 | 6.3 |
| | Afterburner | 53700 | 24358 | 644.4 | 282.2 | 220.2 | 99.9 | 6.4 | 2.9 | 53.7 | 24.4 | | |
| J79-GE-10 GE TJ (Refs. 21, 32) | Idle | 1100 | 499 | 48.0 | 21.8 | 3.2 | 1.5 | 9.8 | 4.4 | 1.1 | 0.5 | 57.8 | 26.2 |
| | 75% Thrust | 6190 | 2808 | 45.6 | 20.7 | 69.9 | 31.7 | 4.1 | 1.9 | 6.2 | 2.8 | 67.0 (nom) | 30.4 |
| | Intermed. (MIL) | 9880 | 4482 | 52.0 | 23.6 | 151.8 | 68.9 | 16.0 | 7.3 | 9.9 | 4.5 | 77.7 | 35.2 |
| | Afterburner | 35390 | 16053 | 611.9 | 277.6 | 241.3 | 109.5 | 17.2 | 7.8 | 35.4 | 16.1 | 299.7 | 135.9 |
| J85-GE-5F GE TJ for T38 (Refs. 21, 23 and 26) | Idle | 524 | 238 | 93.3 | 42.3 | 0.7 | 0.3 | 15.7 | 7.1 | 0.5 | 0.2 | | |
| | 75% (rpm) | 798 | 362 | 62.4 | 28.3 | 1.7 | 0.8 | 1.8 | 0.8 | 0.8 | 0.4 | | |
| | 85% (rpm) | 1098 | 498 | 63.7 | 28.9 | 3.0 | 1.4 | 1.3 | 0.6 | 1.1 | 0.5 | | |
| | 90% (rpm) | 1198 | 543 | 57.6 | 26.1 | 3.7 | 1.7 | 0.9 | 0.4 | 1.2 | 0.5 | | |
| | Intermed. (MIL) | 1297 | 588 | 55.8 | 25.3 | 3.0 | 1.4 | 4.5 | 2.0 | 1.3 | 0.6 | | |
| | Afterburner (Max. ST) | 8470 | 3842 | 245.6 | 111.4 | 22.0 | 10.0 | 6.8 | 3.1 | 8.5 | 3.9 | | |
| J85-GE-21 GE TJ for F-5 (Refs. 21, 23) | Idle | 400 | 181 | 63.6 | 28.4 | 0.5 | 0.2 | 9.7 | 4.4 | 0.4 | 0.2 | | |
| | 75% (rpm) | 700 | 318 | 64.5 | 29.3 | 1.4 | 0.6 | 8.7 | 3.9 | 0.7 | 0.3 | | |
| | 85% (rpm) | 1200 | 544 | 55.4 | 25.1 | 3.5 | 1.6 | 3.1 | 1.4 | 1.2 | 0.5 | | |
| | 90% (rpm) | 1500 | 680 | 54.9 | 24.9 | 5.2 | 2.4 | 1.6 | 0.7 | 1.5 | 0.7 | | |
| | Intermed. (MIL) | 3200 | 1452 | 69.0 | 31.3 | 16.0 | 7.3 | 0.8 | 0.4 | 3.2 | 1.5 | | |
| | Afterburner (Max) (J85-GE-5F data) | 10650 | 4831 | 387.7 | 175.8 | 59.6 | 27.0 | 1.1 | 0.5 | 10.7 | 4.8 | | |

TABLE 5-2 (CONTINUED)

| Turbofan Model-Series (Civil Version) Mgf. Type[g] | Mode | Fuel Rate | | CO | | $NO_x$[a] | | Total HC[b] | | $SO_x$[c] | | Particulates[d,e] | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | lb/hr | kg/hr | lb/hr | kg/hr | lb/hr | kg/hr | lb/hr | kg/hr | lb/hr | kg/hr | lb/hr | kg/hr |
| TF30-P-6B (JFT 10) P&W TF for A-7 (Ref. 21) | Idle | 689 | 313 | 47.0 | 21.3 | 0.9 | 0.4 | 12.9 | 5.9 | 0.7 | 0.3 | | |
| | 75% (Thrust) | 3550 | 1610 | 22.4 | 10.2 | 23.7 | 10.8 | 10.5 | 4.8 | 3.6 | 1.6 | | |
| | Normal Rated | 4700 | 2132 | 26.1 | 11.8 | 37.9 | 17.2 | 6.6 | 3.0 | 4.7 | 2.1 | | |
| | Intermed. (Mil) | 6835 | 3100 | 21.1 | 9.6 | 82.3 | 37.3 | 6.9 | 3.1 | 6.8 | 3.1 | | |
| TF30-P-100 (JFT 10) P&W TF for F-111 (Refs. 26, 32) | Idle | 1260 | 567 | 60.0 | 27.2 | 3.6 | 1.6 | 23.8 | 10.8 | 1.3 | 0.6 | 33.1 | 15.0 |
| | Approach, Intermed. | 6650 | 3016 | 4.7 | 2.1 | 133.0 | 60.3 | 0.7 | 0.3 | 6.7 | 3.0 | 159.6 | 72.4 |
| | | 7120 | 3230 | 5.0 | 2.3 | 199.4 | 90.4 | 0.7 | 0.3 | 7.1 | 3.2 | 59.4 | 26.9 |
| | Military | 42850 | 19437 | 1062.7 | 482.0 | 191.5 | 86.0 | 85.7 | 38.9 | 42.9 | 19.5 | 229.7 | 104.2 |
| | Afterburner | | | | | | | | | | | | |
| TF30-P-412A (JFT 10A) P&W TF) for F-14 (Refs. 21, 32) | Idle | 999 | 453 | 68.1 | 30.9 | 2.4 | 1.1 | 38.4 | 17.4 | 1.0 | 0.5 | 26.5 | 12.0 |
| | 75% (rpm) | 1448 | 6554 | 55.9 | 25.4 | 5.3 | 2.4 | 14.0 | 6.4 | 1.4 | 0.6 | 34.8 | 15.8 |
| | 85% (rpm) | 2598 | 1178 | 39.5 | 17.9 | 18.4 | 8.3 | 2.9 | 1.3 | 2.6 | 1.2 | 46.8 (nom.) | 21.2 |
| | 90% (rpm) | 3597 | 1632 | 22.8 | 10.3 | 34.6 | 15.7 | 0.6 | 0.3 | 3.6 | 1.6 | 54.0 (nom.) | 24.5 |
| | Intermed. (Mil) | 7394 | 3354 | 15.7 | 7.1 | 123.2 | 55.9 | 0.7 | 0.3 | 7.4 | 3.4 | 61.7 | 28.0 |
| | Afterburner | 40000 | 18144 | 600.0 | 272.2 | 270.0 | 122.5 | 40.0 | 18.1 | 40.0 | 18.1 | 693.2 | 314.4 |
| TF33-P-3/5/7 (JT3D) P&W TF (Refs. 26,32,34) | Idle | 846 | 384 | 74.9 | 34.0 | 1.5 | 0.7 | 77.8 | 35.3 | 0.8 | 0.4 | 4.4 | 2.0 |
| | Approach | 3797 | 1722 | 34.2 | 15.5 | 27.7 | 12.6 | 14.4 | 6.5 | 3.8 | 1.7 | 53.1 | 24.1 |
| | Intermed. | 7323 | 3322 | 13.2 | 6.0 | 65.9 | 29.9 | 2.9 | 1.3 | 7.3 | 3.3 | 102.5 | 46.5 |
| | Military | 9979 | 4526 | 13.0 | 5.9 | 109.8 | 49.8 | 3.0 | 1.4 | 10.0 | 4.5 | 79.8 | 36.2 |
| TF34-GE-400 GE TF (Refs.21, 32) | Idle | 457 | 207 | 35.0 | 15.9 | 0.6 | 0.3 | 7.1 | 3.2 | 0.5 | 0.2 | | |
| | 75% (rpm) | 459 | 208 | 11.1 | 5.0 | 1.3 | 0.6 | 1.1 | 0.5 | 0.5 | 0.2 | | |
| | Approach | 1296 | 588 | 19.4 | 8.8 | 10.0 | 4.5 | 0.8 | 0.4 | 1.3 | 0.6 | | |
| | Intermed. (Mil) | 3796 | 1722 | 9.3 | 4.2 | 20.9 | 9.5 | 1.6 | 0.7 | 3.8 | 1.7 | | |
| TF39-GE-1 (JT4A) GE TF (Refs. 26, 32) | Idle | 1130 | 513 | 75.7 | 34.3 | 3.4 | 1.5 | 26.0 | 11.8 | 1.1 | 0.5 | 0.3 | 0.1 |
| | Approach, Intermed. | 5740 | 2604 | 4.0 | 1.8 | 160.7 | 72.9 | 1.1 | 0.5 | 5.7 | 2.6 | 8.0[f] | 3.6 |
| | Military | 11410 | 5176 | 8.0 | 3.6 | 319.5 | 144.9 | 2.3 | 1.0 | 11.4 | 5.2 | 17.1[f] | 7.8 |
| TF41-A-2 All. TF (Ref. 21) | Idle | 1070 | 485 | 114.6 | 52.0 | 1.4 | 0.6 | 70.8 | 32.1 | 1.1 | 0.5 | | |
| | Approach (62% Thrust) | 5314 | 2410 | 27.5 | 12.5 | 56.6 | 25.7 | 12.9 | 5.9 | 5.3 | 2.4 | | |
| | Intermed. (Mil) | 9040 | 4101 | 14.4 | 6.5 | 201.4 | 91.4 | 5.3 | 2.4 | 9.0 | 4.1 | | |
| F100-PW-100 (JTF 22) P&W TF (Ref. 32) | Idle | 1060 | 481 | 20.5 | 9.3 | 4.2 | 1.9 | 2.4 | 1.1 | 1.1 | 0.5 | 0.1[f] | 0.05 |
| | Approach | 3000 | 1361 | 9.0 | 4.1 | 33.0 | 15.0 | 1.8 | 0.8 | 3.0 | 1.4 | 1.0[f] | 0.5 |
| | Military | 10400 | 4717 | 18.7 | 8.5 | 457.6 | 207.6 | 0.5 | 0.2 | 10.4 | 4.7 | 8.6[f] | 3.9 |
| | Afterburner | 44200 | 20049 | 2435.4 | 1104.7 | 729.3 | 330.8 | 4.4 | 2.0 | 44.2 | 20.1 | 0.0[f] | 0.0 |

TABLE 5-2 (CONTINUED)

| Turboprop/Shaft Model-Series (Civil Version) Mfg. Type[g] | Mode | Fuel Rate | | CO | | $NO_x$[a] | | Total HC[b] | | $SO_x$[c] | | Particulates[d,e] | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | lb/hr | kg/hr | lb/hr | kg/hr | lb/hr | kg/hr | lb/hr | kg/hr | lb/hr | kg/hr | lb/hr | kg/hr |
| PT6A-27 | Idle | 115 | 52 | 7.36 | 3.34 | 0.28 | 0.13 | 5.77 | 2.62 | 0.12 | 0.05 | | |
| PWC TP | Takeoff | 425 | 193 | 0.43 | 0.20 | 3.32 | 1.51 | 0 | 0 | 0.43 | 0.20 | | |
| (Ref. 2) | Climbout | 400 | 181 | 0.48 | 0.22 | 2.80 | 1.27 | 0 | 0 | 0.40 | 0.18 | | |
| | Approach | 215 | 98 | 5.0 | 2.24 | 1.80 | 0.82 | 0.47 | 0.21 | 0.22 | 0.10 | | |
| T53-L-11D | Ground Idle | 142 | 64 | 4.2 | 1.9 | 0.2 | 0.1 | 9.0 | 4.1 | 0.14 | 0.06 | | |
| (LTC1) | Normal Rated | 635 | 288 | 3.7 | 1.7 | 3.8 | 1.7 | 0.3 | 0.1 | 0.64 | 0.29 | | |
| Lyc TS | Intermed. (Mil) | 674 | 306 | 1.9 | 0.9 | 3.7 | 1.7 | 0.1 | 0.05 | 0.67 | 0.30 | | |
| (Ref. 21) | Takeoff/Landing | 679 | 308 | 2.0 | 0.9 | 5.0 | 2.3 | 0.2 | 0.1 | 0.68 | 0.31 | | |
| T55-L-11A | Ground Idle | | | 29.5 | 13.4 | 0.8 | 4.0 | 4.0 | 1.8 | | | | |
| (LTC4) | 60% (Thrust) | | | 12.9 | 5.9 | 9.1 | 4.1 | 0.3 | 0.1 | | | | |
| Lyc TS | Intermed. (Mil) | | | 14.5 | 6.6 | 18.6 | 8.4 | 0.2 | 0.1 | | | | |
| (Ref. 21) | Maximum | | | 12.9 | 5.9 | 14.5 | 6.6 | 0.2 | 0.1 | | | | |
| T56-A7 | Low Speed Idle | 548 | 249 | 17.5 | 7.9 | 2.1 | 1.0 | 11.5 | 5.2 | 0.5 | 0.2 | 1.6 | 0.7 |
| All TP | Approach | 1053 | 478 | 3.7 | 1.7 | 7.8 | 3.5 | 0.5 | 0.2 | 1.1 | 0.5 | 3.0 | 1.4 |
| (Refs. 1,2 6, 32) | Intermediate, Climbout | 1908 | 865 | 4.6 | 2.1 | 17.6 | 8.0 | 0.9 | 0.4 | 0.9 | 0.9 | 3.0 | 1.4 |
| | Military, Takeoff | 2079 | 943 | 4.4 | 2.0 | 19.3 | 8.8 | 0.8 | 0.4 | 2.1 | 1.0 | 3.7 | 1.7 |
| T58-GE-5 | Idle | 133 | 60 | 22.5 | 10.2 | 0.2 | 0.1 | 12.9 | 5.9 | 0.1 | 0.05 | 0.1 | 0.05 |
| GE TS | Intermed. (Mil) | 821 | 372 | 5.6 | 2.5 | 5.5 | 2.5 | 2.7 | 1.2 | 0.8 | 0.4 | 0.8 | 0.4 |
| (Ref. 21) | Power Takeoff | 886 | 402 | 5.0 | 2.3 | 6.4 | 2.9 | 0.7 | 0.3 | 0.9 | 0.4 | 0.8 | 0.4 |
| | Normal Cruise | 757 | 343 | 5.8 | 2.6 | 4.8 | 2.2 | 1.2 | 0.5 | 0.8 | 0.4 | 0.6 | 0.3 |
| T63-A-5A | Ground Idle | 50 | 23 | 5.6 | 2.5 | 0.1 | 0.05 | 2.4 | 1.1 | 0.05 | 0.02 | | |
| (Model 250) | 60% Thrust | 143 | 65 | 3.9 | 1.8 | 0.6 | 0.3 | 0.5 | 0.2 | 0.1 | 0.05 | | |
| All TS | 75% Thrust | 169 | 77 | 3.1 | 1.4 | 0.7 | 0.3 | 0.3 | 0.1 | 0.2 | 0.1 | | |
| (Ref. 21) | Intermed. (Mil) | 207 | 94 | 1.8 | 0.8 | 1.1 | 0.5 | 0.3 | 0.1 | 0.2 | 0.1 | | |
| T64-GE-6B | Idle | 337 | 153 | 16.4 | 7.4 | 1.3 | 0.6 | 4.4 | 2.0 | 0.3 | 0.1 | 0.1 | 0.05 |
| GE TS | 75% (hp) | 1039 | 471 | 4.9 | 2.2 | 9.3 | 4.2 | 0.8 | 0.4 | 1.0 | 0.5 | 0.6 | 0.3 |
| (Ref. 21) | Normal Rated | 1257 | 570 | 3.6 | 1.6 | 13.1 | 5.9 | 0.9 | 0.4 | 1.3 | 0.6 | 0.9 | 0.4 |
| | Intermed. (Mil) | 1390 | 630 | 3.2 | 1.5 | 15.5 | 7.0 | 0.9 | 0.4 | 1.4 | 0.6 | 1.1 | 0.5 |
| T76 | Idle | 192 | 87 | 4.6 | 2.1 | 1.4 | 0.6 | 1.4 | 0.6 | 0.2 | 0.09 | | |
| (TPE 331-1) | Normal-Cruise | 347 | 157 | 2.1 | 1.0 | 3.4 | 1.5 | 0.04 | 0.02 | 0.3 | 0.1 | | |
| GA TP | Military | 387 | 176 | 0.9 | 0.4 | 4.0 | 1.8 | 0.02 | 0.01 | 0.4 | 0.2 | | |
| (Ref. 34) | | | | | | | | | | | | | |

TABLE 5-2 (CONCLUDED)

| Model-Series (Civil Version) Mfg. Type[g] | Mode | Fuel Rate | | CO | | NO[a] | | Total HC[b] | | $SO_x$[c] | | Particulates[d,e] | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | lb/hr | kg/hr | lb/hr | kg/hr | lb/hr | kg/hr | lb/hr | kg/hr | lb/hr | kg/hr | lb/hr | kg/hr |
| TPE 331-2 | Idle | 105 | 47.6 | 6.7 | 3.1 | 0.3 | 0.1 | 9.6 | 4.3 | 0.1 | 0.05 | | |
| GA TP | Takeoff | 405 | 183.7 | 0.4 | 0.2 | 4.1 | 1.9 | 0.2 | 0.07 | 0.4 | 0.2 | | |
| (Ref. 2) | Climbout | 372 | 168.7 | 0.5 | 0.2 | 3.7 | 1.7 | 0.2 | 0.07 | 0.4 | 0.2 | | |
| | Approach | 220 | 99.8 | 3.7 | 1.7 | 1.8 | 0.8 | 0.6 | 0.3 | 0.2 | 0.1 | | |
| T400-CP-400 | Ground Idle | 136 | 62 | 3.8 | 1.7 | 0.3 | 0.1 | 1.3 | 0.6 | 0.1 | 0.04 | 0.06 | 0.03 |
| (PT6T Twin | Flight idle | 141 | 64 | 4.1 | 1.9 | 0.4 | 0.2 | 1.1 | 0.5 | 0.1 | 0.04 | | |
| Pak) PWC TS | Cruise Speed | 279 | 127 | 0.5 | 0.2 | 1.3 | 0.6 | 0.0 | 0 | 0.3 | 0.1 | 0.1 (nom) | 0.05 |
| (Refs. 21, 23) | Intermed. (Mil) | 406 | 184 | 0.0 | 0 | 2.4 | 1.1 | 0.0 | 0 | 0.4 | 0.2 | 0.1 (nom) | 0.05 |
| | Maximum | 1069 | 485 | 0.0 | 0 | 12.3 | 5.6 | 0.2 | 0.1 | 1.0 | 0.5 | 0.3 | 0.14 |
| IO-360C | Idle | 15.2 | 6.9 | 12.9 | 5.9 | 0.02 | 0.01 | 2.2 | 1.0 | 0.00 | 0.0 | | |
| Con O | Approach | 67.9 | 30.8 | 66.0 | 30.0 | 0.4 | 0.2 | 1.2 | 0.5 | 0.01 | 0.0 | | |
| (Ref. 32) | Military | 88.7 | 40.2 | 91.5 | 41.5 | 0.5 | 0.2 | 2.0 | 0.9 | 0.02 | 0.01 | | |
| O-470C | Idle | 15.1 | 6.8 | 11.2 | 5.1 | 0.02 | 0.01 | 2.9 | 1.3 | 0.00 | 0.0 | | |
| Con O | Approach | 85.6 | 38.8 | 59.2 | 26.9 | 0.8 | 0.4 | 0.8 | 0.4 | 0.02 | 0.01 | | |
| (Ref. 32) | Military | 131.3 | 59.6 | 151.7 | 68.8 | 0.1 | 0.05 | 0.4 | 0.2 | 0.03 | 0.01 | | |
| R-1820-82 | Idle | 89 | 40.3 | 42.2 | 19.1 | 0.0 | 0 | 13.4 | 6.1 | 0.02 | 0.01 | | |
| Wr R | Approach | 323 | 147 | 124.3 | 56.3 | 2.1 | 1.0 | 1.8 | 0.8 | 0.06 | 0.03 | | |
| (Ref. 21) | Climbout | 862 | 391 | 375.0 | 170.1 | 1.8 | 0.8 | 41.8 | 19.0 | 0.2 | 0.09 | | |
| | Takeoff | 1166 | 529 | 620.0 | 281.2 | 2.0 | 0.9 | 110.4 | 50.0 | 0.2 | 0.09 | | |

[a] Nitrogen oxides reported as $NO_2$. Some authors assume 88 wt% NO, rest $HNO_3$ in combustion water (Ref. 33).

[b] Hydrocarbons. Includes unburned hydrocarbons and organic pyrolysis products.

[c] Sulfur oxides and sulfuric acid reported as $SO_2$. Calculated from fuel rate and 0.05 wt% sulfur in JP-4 or JP-5 fuel, or 0.01 wt% sulfur in aviation gasoline. For turbine engines, the conversion is therefore $SO_x$ (lb/hr) = $10^{-3}$ (fuel rate), and for piston engines, the conversion is $SO_x$ (lb/hr) = $2 \times 10^{-4}$ (fuel rate).

[d] Includes all "condensible particulates," and, thus may be much higher than solid particulates alone (Ref. 32).

[e] "Nom." data are assumed for calculational purposes, in the absence of experimental data.

[f] Dry particles only.

[g] For abbreviations, cf. footnote, Table 4-1.

The number of significant figures reported in Tables 5-1, 5-2 and 6-1 and 6-2 does not imply a corresponding precision. Rather, the significant figures are carried to avoid accumulation of rounding errors.

# 6. EMISSION FACTORS PER LTO CYCLE

## 6.1 CIVIL DATA

As discussed in Section 4.1, most of the civil aircraft emission factor data were supplied by the USEPA Office of Mobile Source Air Pollution Control, and simply rearranged as noted earlier. The conversion from modal emission rates to emission factors per LTO cycle is described in Section 4.4. The results of this conversion appear in Tables 6-1 and 6-2.

## 6.2 MILITARY DATA

Military data appear in Table 6-3. As noted previously, for many engines there are multiple power setting options, often many more than were selected to appear in the Modal Emission Rate table. In order to define in Table 6-3 the selection of power settings from Table 5-2, a "modes code" was introduced. This is explained in footnote b. Conversion from data of Table 5-2 to those of Table 6-3 was performed as described earlier in Section 4.4.

The reader should bear in mind the restrictions and assumptions implicit in these tabulations. As discussed in Section 4.3, these include the altitudes for which the TIMs apply, the engine power settings assumed, the fact that military training exercises involve a great many "touch and go" LTO cycles, and because military ground idle times vary greatly, depending on specific missions. The civil aircraft data correspond only to periods of heavy activity at large, congested metropolitan airports. "Tough and go" practice may be important at some civil airports.

In conclusion, one might quote AP-42:

> "The reader must be herein cautioned not to use these emission factors indiscriminately. That is, the factors generally will not permit the calculation of accurate emissions measurements from an individual installation.....Factors are more valid when applied to a large number of processes, as, for example, when emission inventories are conducted as part of community or nationwide air pollution studies."

TABLE 6-1. CIVIL AIRCRAFT, COMMERCIAL CARRIER – EMISSION FACTORS PER AIRCRAFT PER LANDING-TAKEOFF CYCLE (REF. 2)

| Aircraft | Power Plant[a] | | | CO | | $NO_x$[b] | | Total HC[c] | | $SO_x$[d] | | Particulates | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | No. | Mfg. | Model-Series | lb | kg | lb | kg | lb | kg | lb | kg | lb | kg |
| **Short, Medium, Long Range and Jumbo Jets** | | | | | | | | | | | | | |
| BAC/Aerospatiale Concorde | 4 | RR | Olymp 593 | 847.0 | 384.0 | 91.0 | 41.0 | 246.0 | 112.0 | 14.1 | 6.4 | | |
| BAC 111-400 | 2 | RR | Spey 511 | 103.36 | 46.88 | 15.04 | 6.82 | 72.42 | 32.85 | 1.70 | 0.77 | 1.46 | 0.66 |
| Boeing 707-320B | 4 | P&W | JT3D-7 | 262.64 | 119.12 | 25.68 | 11.64 | 218.24 | 99.00 | 4.28 | 1.94 | 4.52 | 2.05 |
| Boeing 727-200 | 3 | P&W | JT8D-17 | 55.95 | 25.38 | 29.64 | 13.44 | 13.44 | 6.09 | 3.27 | 1.48 | 1.17 | 0.53 |
| Boeing 737-200 | 2 | P&W | JT8D-17 | 37.30 | 16.92 | 19.76 | 8.96 | 8.96 | 4.06 | 2.18 | 0.99 | 0.78 | 0.35 |
| Boeing 747-200B | 4 | P&W | JT9D-7 | 259.64 | 117.76 | 83.24 | 37.76 | 96.92 | 43.96 | 7.16 | 3.25 | 5.20 | 2.36 |
| Boeing 747-200B | 4 | P&W | JT9D-70 | 108.92 | 49.40 | 107.48 | 48.76 | 22.40 | 10.16 | 7.96 | 3.61 | 5.20 | 2.36 |
| Boeing 747-200B | 4 | RR | RB211-524 | 66.76 | 30.28 | 124.9 | 56.65 | 10.00 | 4.54 | 7.52 | 3.41 | | |
| Lockheed L1011-200 | 3 | RR | RB211-524 | 50.07 | 27.71 | 93.66 | 42.48 | 7.50 | 3.40 | 5.64 | 2.56 | | |
| Lockheed L1011-100 | 3 | RR | RB211-22B | 199.4 | 90.44 | 64.29 | 29.16 | 138.4 | 62.77 | 4.95 | 2.24 | | |
| McDonnell-Douglas DC8-63 | 4 | P&W | JT3D-7 | 262.64 | 119.12 | 25.68 | 11.64 | 218.24 | 99.00 | 3.27 | 1.48 | 1.17 | 0.53 |
| McDonnell-Douglas DC9-50 | 2 | P&W | JT8D-17 | 37.30 | 16.92 | 19.76 | 8.96 | 8.96 | 4.06 | 2.18 | 0.99 | 0.78 | 0.35 |
| McDonnell-Douglas DC10-30 | 3 | GE | CF6-50C | 116.88 | 53.01 | 49.59 | 22.17 | 47.10 | 21.36 | 4.98 | 2.26 | 0.21 | 0.10 |
| **Air Carrier Turboprops – Commuter, Feeder Line and Freighters** | | | | | | | | | | | | | |
| Beech 99 | 2 | PWC | PT6A-28 | 7.16 | 3.25 | 0.82 | 0.37 | 5.08 | 2.30 | 0.18 | 0.08 | | |
| GD/Convair 580 | 2 | All | 501 | 24.38 | 11.06 | 21.66 | 9.82 | 9.82 | 4.45 | 0.92 | 0.42 | | |
| DeHavilland Twin Otter | 2 | PWC | PT6A-27 | 7.16 | 3.25 | 0.82 | 0.37 | 5.08 | 2.30 | 0.18 | 0.08 | | |
| Fairchild F27 and FH227 | 2 | RR | R.Da.7 | 36.26 | 16.45 | 0.92 | 0.42 | 22.42 | 10.17 | 0.58 | 0.26 | | |
| Grumman Goose | 2 | PWC | PT6A-27 | 7.16 | 3.25 | 0.82 | 0.37 | 5.08 | 2.30 | 0.18 | 0.08 | | |
| Lockheed L188 Electra | 4 | All | 501 | 48.76 | 22.12 | 43.32 | 19.65 | 19.64 | 8.91 | 1.84 | 0.83 | | |
| Lockheed L100 Hercules | 4 | All | 501 | 48.76 | 22.12 | 43.32 | 19.65 | 19.64 | 8.91 | 1.84 | 0.83 | | |
| Swearingen Metro-2 | 2 | GA | TPE 331-3 | 6.26 | 2.84 | 1.16 | 0.53 | 7.68 | 3.48 | 0.16 | 0.07 | 0.46 | 0.21 |

[a] Abbreviations: All – Detroit Diesel Allison Division of General Motors; Con – Teledyne/Continental; GA – Garrett AiResearch; GE – General Electric; Lyc – Avco/Lycoming; P&W – Pratt & Whitney; PWC – Pratt & Whitney Aircraft of Canada; RR – Rolls Royce.

[b] Nitrogen oxides reported as $NO_2$.

[c] Total hydrocarbons (Volatile organics, including unburned hydrocarbons and organic pyrolysis products.)

[d] Sulfur oxides and sulfuric acid reported as $SO_2$.

TABLE 6-2. CIVIL AIRCRAFT, GENERAL AVIATION – EMISSION FACTORS PER AIRCRAFT PER LANDING-TAKEOFF CYCLE (REF. 2)

| Aircraft | Power Plant[a] | | | CO | | $NO_x$[b] | | Total HC[c] | | $SO_x$[d] | | Particulates | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | No. | Mfg. | Model-Series | lb | kg | lb | kg | lb | kg | lb | kg | lb | kg |
| **Business Jets** | | | | | | | | | | | | | |
| Cessna Citation | 2 | P&W | JT15D-1 | 19.50 | 8.85 | 2.00 | 0.91 | 6.72 | 3.05 | 0.40 | 0.18 | | |
| Dassault Falcon 20 | 2 | GE | CF700-2D | 76.14 | 34.54 | 1.68 | 0.76 | 7.40 | 3.36 | 0.78 | 0.35 | | |
| Gates Learjet 24D | 2 | GE | CJ610-6 | 88.76 | 40.26 | 1.58 | 0.72 | 8.42 | 3.82 | 0.84 | 0.38 | | |
| Gates Learjet 35, 36 | 2 | GE | TPE 731-2 | 11.26 | 5.11 | 3.74 | 1.58 | 3.74 | 1.70 | 0.92 | 0.42 | | |
| Rockwell International Shoreliner 75A | 2 | GE | CF 700 | 76.14 | 34.54 | 1.08 | 0.76 | 7.40 | 3.36 | 0.78 | 0.35 | | |
| **Business Turboprops (EPA Class P2)** | | | | | | | | | | | | | |
| Beech B99 Airliner | 2 | PWC | PT6A-27 | 7.16 | 3.25 | 0.82 | 0.37 | 5.08 | 2.30 | 0.18 | 0.08 | | |
| DeHavilland Twin Otter | 2 | PWC | PT6A-27 | 7.16 | 3.25 | 0.82 | 0.37 | 5.08 | 2.30 | 0.18 | 0.08 | | |
| Shorts Skyvan-3 | 2 | GA | TPE-331-2 | 6.44 | 2.92 | 0.883 | 0.400 | 8.40 | 3.81 | 0.16 | 0.07 | 0.46 | 0.21 |
| Swearingen Merlin IIIA | 2 | GA | TPE-331-3 | 6.28 | 2.85 | 1.15 | 0.522 | 7.71 | 3.50 | 0.16 | 0.07 | 0.46 | 0.21 |
| **General Aviation Piston (EPA Class P1)** | | | | | | | | | | | | | |
| Cessna 150 | 1 | Con | O-200 | 8.32 | 3.77 | 0.02 | 0.01 | 0.23 | 0.10 | 0.0 | 0.0 | | |
| Piper Warrior | 1 | Lyc | O-320 | 14.37 | 6.52 | 0.02 | 0.01 | 0.26 | 0.12 | 0.0 | 0.0 | | |
| Cessna Pressurized Skymaster | 2 | Con | TS10-360C | 33.10 | 15.01 | 0.13 | 0.06 | 1.15 | 0.52 | 0.0 | 0.0 | | |
| Piper Navajo Chieftain | 2 | Lyc | T10-540 | 96.24 | 43.65 | 0.02 | 0.01 | 1.76 | 0.80 | 0.0 | 0.0 | | |

[a]Abbreviations: All – Detroit Diesel Allison Division of General Motors; Con – Teledyne/Continental; GA – Garrett AiResearch; GE – General Electric; Lyc – Avco/Lycoming; P&W – Pratt & Whitney; PWC – Pratt & Whitney Aircraft of Canada; RR – Rolls Royce.

[b]Nitrogen oxides reported as $NO_2$.

[c]Total hydrocarbons (Volatile organics, including unburned hydrocarbons and organic pyrolysis products.)

[d]Sulfur oxides and sulfuric acid reported as $SO_2$.

TABLE 6-3. MILITARY AIRCRAFT – EMISSION FACTORS PER AIRCRAFT PER LANDING-TAKEOFF CYCLE

| Aircraft | | Power Plant | | Codes | | Emissions per LTO Cycle | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DOD Desig. | Popular Name | No. | Model – Series | TIM[a] | Modes[b] | CO | | $NO_x$[c] | | Total HC[d] | | $SO_x$[e] | | Particulates[f] | |
| | | | | | | lb | kg | lb | kg | lb | kg | lb | kg | lb | kg |
| **Fixed Wing – Turbine** | | | | | | | | | | | | | | | |
| A-4C | Skyhawk | 1 | J65-W-20 | 2 | 1553 | 16.62 | 7.54 | 2.15 | 0.98 | 1.10 | 0.50 | 0.46 | 0.21 | | |
| A-6 | Intruder | 2 | J52-P-6B | 2 | 1553 | 45.26 | 20.53 | 3.44 | 1.56 | 5.52 | 2.50 | 1.58 | 0.72 | | |
| A-7A | Corsair 2 | 1 | TF30-P-6B | 2 | 1442 | 11.10 | 5.03 | 2.05 | 0.93 | 3.18 | 1.44 | 0.35 | 0.16 | | |
| A-E/G | Corsair 2 | 1 | TF41-A-2 | 2 | 1332 | 25.79 | 11.70 | 4.83 | 2.19 | 15.76 | 7.15 | 0.52 | 0.24 | | |
| A-10 | --------- | 2 | TF34-GE-400 | 1 | 1443 | 37.38 | 16.96 | 2.60 | 1.18 | 7.22 | 3.27 | 0.80 | 0.36 | | |
| A-37 | Dragon Fly | 2 | J69-T-25 | 1 | 1332 | 55.28 | 25.08 | 2.66 | 1.21 | 3.58 | 1.62 | 0.60 | 0.27 | | |
| B-52G | Stratofortress | 8 | J57-P-22 | 7 | 1553 | 441.76 | 200.38 | 49.28 | 22.35 | 371.12 | 168.34 | 10.72 | 4.86 | 63.44 | 28.78 |
| B-52H | Stratofortress | 8 | TF-33-P-3/5/7 | 7 | 1432 | 504.08 | 228.65 | 53.04 | 24.06 | 505.76 | 229.41 | 10.24 | 4.64 | 94.08 | 42.67 |
| F-4 | Phantom 2 | 2 | J79-GE-10 | 2 | 1432 | 32.24 | 14.62 | 10.88 | 4.94 | 4.94 | 2.24 | 1.46 | 0.66 | 33.92 | 15.39 |
| F-5 | Freedom Fighter/Tiger 2 | 2 | J85-GE-21 | 1 | 1653 | 76.64 | 34.76 | 2.10 | 0.95 | 10.04 | 4.55 | 0.76 | 0.34 | | |
| F-8 | Crusader | 1 | J57-P-22 | 1 | 1653 | 41.82 | 18.97 | 5.60 | 2.54 | 28.44 | 12.90 | 1.19 | 0.54 | | |
| F-14 | Tomcat | 2 | TF30-P-412A | 2 | 1653 | 39.88 | 18.09 | 7.62 | 3.46 | 17.36 | 7.87 | 1.24 | 0.56 | 24.24 | 11.00 |
| F-15A | Eagle | 2 | F100-PW-100 | 1 | 1432 | 54.40 | 24.66 | 29.96 | 13.58 | 2.68 | 1.22 | 2.32 | 1.06 | 0.44 | 0.20 |
| F-16 | --------- | 1 | F100-PW-100 | 1 | 1432 | 27.20 | 12.34 | 14.98 | 6.79 | 1.34 | 0.61 | 1.16 | 0.53 | 0.22 | 0.10 |
| F-100 | Super Sabre | 1 | J57-P-22 | 1 | 1653 | 41.82 | 18.97 | 5.61 | 2.54 | 28.44 | 12.90 | 1.19 | 0.54 | | |
| F-106 | Delta Dart | 1 | J75-P-17 | 1 | 1432 | 69.65 | 31.59 | 11.84 | 5.37 | 48.17 | 21.85 | 2.04 | 0.93 | | |
| F-111 | --------- | 2 | TF30-P-100 | 1 | 1432 | 74.44 | 33.77 | 26.94 | 12.22 | 24.86 | 11.28 | 2.82 | 1.28 | 56.12 | 25.46 |
| C-2 | Greyhound | 2 | T56-A-7 | 6 | 1432 | 16.18 | 7.34 | 4.80 | 2.17 | 10.14 | 4.60 | 0.80 | 0.36 | 2.18 | 0.99 |
| C-5A | Galaxy | 4 | TF39-GE-1 | 5 | 1322 | 82.12 | 37.25 | 79.60 | 36.11 | 28.08 | 12.74 | 3.84 | 1.74 | 4.12 | 1.87 |
| C-9 | Nightingale/Skytrain 2 | 2 | JT8D-17 | 5 | Civ. Table | 24.60 | 11.16 | 13.02 | 5.91 | 5.62 | 2.55 | 1.56 | 0.71 | 0.62 | 0.28 |
| C-12 | Huron | 2 | PT6A-27 | 5 | 1234 | 4.78 | 2.16 | 0.60 | 0.27 | 1.12 | 0.51 | 0.12 | 0.05 | | |
| C-130 | Hercules | 4 | T56-A-7 | 6 | 1432 | 32.36 | 14.68 | 9.60 | 4.35 | 20.28 | 9.20 | 1.60 | 0.73 | 4.36 | 1.98 |
| KC-135 | Stratotanker | 4 | J57-P-22 | 7 | 1552 | 220.92 | 100.21 | 24.64 | 11.18 | 185.56 | 84.17 | 5.36 | 2.43 | 31.36 | 14.22 |
| C-141 | Starlifter | 4 | TF33-P-3/5/7 | 5 | 1432 | 92.40 | 41.91 | 19.20 | 8.71 | 87.68 | 39.77 | 3.00 | 1.36 | 33.00 | 14.97 |
| T-2 | Buckeye | 2 | J85-GE-5F | 2 | 1653 | 48.04 | 21.79 | 0.84 | 0.38 | 7.06 | 3.20 | 0.40 | 0.18 | | |
| T-34C | Turbo Mentor | 1 | PT6A-27 | 2 | 1234 | 1.73 | 0.78 | 0.15 | 0.07 | 1.27 | 0.58 | 0.03 | 0.01 | | |
| T-37 | Tweet | 2 | J69-T-25 | 3 | 1332 | 38.40 | 17.42 | 2.22 | 1.01 | 2.26 | 1.03 | 0.46 | 0.21 | | |
| T-38 | Talon | 2 | J85-GE-5F | 3 | 1653 | 72.72 | 32.99 | 1.22 | 0.55 | 10.42 | 4.73 | 0.62 | 0.28 | | |
| T-44 | --------- | 2 | PT6A-27 | 2 | 1234 | 3.46 | 1.57 | 0.30 | 0.14 | 2.54 | 1.15 | 0.06 | 0.03 | | |
| P-3C | Orion | 4 | T56-A-7 | 6 | 1432 | 32.36 | 14.68 | 9.60 | 4.35 | 20.28 | 9.20 | 1.60 | 0.73 | 4.36 | 1.98 |
| S-3A | Viking | 2 | TF34-GE-400 | 6 | 1443 | 34.18 | 15.50 | 4.04 | 1.83 | 6.44 | 2.92 | 1.02 | 0.46 | | |
| E-2 | Hawkeye | 2 | T56-A-7 | 6 | 1432 | 16.18 | 7.34 | 4.80 | 2.17 | 10.14 | 4.60 | 0.80 | 0.36 | 2.18 | 0.99 |
| E-3A | AWACS | 4 | TF-33-P-3/5/7 | 5 | 1432 | 92.40 | 41.91 | 19.20 | 8.71 | 87.68 | 39.77 | 3.00 | 1.36 | 33.00 | 14.97 |
| U-21 | Ute | 2 | PT6A-27 | 5 | 1234 | 4.78 | 2.17 | 0.06 | 0.03 | 3.12 | 1.42 | 0.12 | 0.05 | | |
| AU-24 | Stallion | 1 | PT6A-27 | 5 | 1234 | 2.39 | 1.08 | 0.03 | 0.01 | 1.56 | 0.71 | 0.06 | 0.03 | | |

TABLE 6-3 (CONCLUDED)

| Aircraft | | Power Plant | | Codes | | Emissions per LTO Cycle | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | CO | | $NO_x$[c] | | Total HC[d] | | $SO_x$[e] | | Particulates[f] | |
| DOD Desig. | Popular Name | No. | Model – Series | TIM[a] | Modes[b] | lb | kg | lb | kg | lb | kg | lb | kg | lb | kg |
| **Fixed Wing – Piston** | | | | | | | | | | | | | | | |
| C-1 | Trader | 2 | R-1820-82 | 8 | 1432 | 112.44 | 51.00 | 0.66 | 0.30 | 15.24 | 6.92 | 0.04 | 0.02 | | |
| T-28 | Trojan | 1 | R-1820-82 | 8 | 1432 | 56.22 | 25.50 | 0.33 | 0.15 | 7.62 | 3.46 | 0.02 | 0.01 | | |
| T-34 | Mentor | 1 | O-470C | 8 | 1332 | 21.12 | 9.58 | 0.07 | 0.03 | 0.71 | 0.32 | 0 | 0 | | |
| T-41 | Mescelero | 1 | IO-360C | 8 | 1332 | 16.41 | 7.44 | 0.08 | 0.04 | 0.76 | 0.34 | 0 | 0 | | |
| O-1 | Bird Dog | 1 | O-470C | 8 | 1332 | 21.12 | 9.58 | 0.07 | 0.03 | 0.71 | 0.32 | 0 | 0 | | |
| O-2 | --------- | 2 | IO-360C | 8 | 1332 | 32.82 | 14.88 | 0.16 | 0.08 | 1.52 | 0.68 | 0 | 0 | | |
| S-2 | Tracker | 2 | R-1820-82 | 8 | 1432 | 112.44 | 51.00 | 0.66 | 0.30 | 15.24 | 6.92 | 0.04 | 0.02 | | |
| **Helicopters – Turbine and Piston** | | | | | | | | | | | | | | | |
| UH-1H | Iroquois/Huey | 1 | T53-L-11D | 9 | 1-44 | 1.55 | 0.70 | 1.19 | 0.54 | 2.53 | 1.15 | 0.20 | 0.09 | | |
| UH-1N | Twin Huey | 2 | T-400-CP-400 | 9 | 1-44 | 1.90 | 0.86 | 1.24 | 0.56 | 0.64 | 0.29 | 0.24 | 0.11 | 0.08 | 0.04 |
| AH-1G | Huey Cobra | 1 | T53-L-11D | 9 | 1-44 | 1.55 | 0.70 | 1.19 | 0.54 | 2.53 | 1.15 | 0.20 | 0.09 | | |
| SH-2D/F | Seasprite | 2 | T58-GE-5 | 9 | 1-33 | 13.54 | 6.14 | 3.02 | 1.37 | 6.78 | 3.08 | 0.44 | 0.20 | 0.40 | 0.18 |
| HH-3 | Sea King/Jolly Green Giant | 2 | T58-GE-5 | 9 | 1-33 | 13.54 | 6.14 | 3.02 | 1.37 | 6.78 | 3.08 | 0.44 | 0.20 | 0.40 | 0.18 |
| OH-6A | Cayuse | 1 | T63-A-5A | 9 | 1-32 | 2.19 | 0.99 | 0.31 | 0.14 | 0.69 | 0.31 | 0.05 | 0.02 | | |
| HH-43 | Huskie/Mixmaster | 1 | T53-L-11D | 9 | 1-44 | 1.55 | 0.70 | 1.19 | 0.54 | 2.53 | 1.15 | 0.20 | 0.09 | | |
| CH-46 | Sea Knight | 2 | T58-GE-5 | 9 | 1-33 | 13.54 | 6.14 | 3.02 | 1.37 | 6.78 | 3.08 | 0.44 | 0.20 | 0.40 | 0.18 |
| CH-47 | Chinook | 2 | T55-L-11A | 9 | 1-32 | 20.94 | 9.50 | 6.68 | 3.03 | 2.10 | 0.95 | | | | |
| HH-52 | --------- | 1 | T58-GE-5 | 9 | 1-33 | 6.77 | 3.07 | 1.51 | 0.68 | 3.39 | 1.54 | 0.22 | 0.10 | 0.20 | 0.09 |
| CH-53 | Sea Stallion | 2 | T64-GE-6B | 9 | 1-22 | 10.44 | 4.74 | 4.84 | 2.20 | 2.56 | 1.16 | 0.60 | 0.27 | 0.32 | 0.15 |
| HH-53 | Super Jolly | 2 | T64-GE-6B | 9 | 1-22 | 10.44 | 4.74 | 4.84 | 2.20 | 2.56 | 1.16 | 0.60 | 0.27 | 0.32 | 0.15 |
| OH-58 | Kiowa | 1 | T63-A-5A | 9 | 1-32 | 2.19 | 0.99 | 0.31 | 0.14 | 0.69 | 0.31 | 0.05 | 0.02 | | |

[a] The TIM code is defined in Table 4-5.

[b] The four digits of the modes code identify the four line items in Table 5-2 used to calculate modal emissions contributions for Taxi/Idle, Takeoff, Climbout and Approach, respectively. For example, for the F4 Phantom with J79-GE-10 engines, the modes code is 1432. This means that in the J79 engine entry of Table 5-2,

Line 1 (Idle data) were selected to calculate the Taxi/Idle contribution.
Line 4 (Afterburner data) were selected to calculate the Takeoff contribution.
Line 3 (Intermediate (MIL) data) were selected to calculate the Climbout contribution.
Line 2 (75% Thrust data) were selected to calculate the Approach contribution.

For helicopters, there is no takeoff mode. This is indicated by a dash.

[c] Nitrogen oxides reported is $NO_2$.

[d] Total hydrocarbons. Includes unburned hydrocarbons and organic pyrolysis products.

[e] Sulfur oxides and sulfuric acid reported as $SO_2$.

[f] See footnotes d, e for Table 5-2.

# 7. AUXILIARY POWER UNITS

Auxiliary power units (APUs) are employed to produce power for aircraft services when the main engines are not running. Usually APUs are off when main engines are running, i.e., taxiing and flying. Because aircraft power requirements are fairly constant (except for air conditioning), APU power level is dependent largely upon the passenger load and upon the weather (Ref. 35).

There is no duty cycle in usual terms. In order to use the data in the accompanying table, the reader will need to acquire local data on the times for which aircraft are parked at ramps or hangers and on auxiliary power.

TABLE 7-1. AUXILIARY POWER UNIT EMISSION RATES (REF. 35[a])

| APU Engine | Manufacturer | Size[b] | Aircraft | Fuel Rate | | CO[c] | | $NO_x$[c] | | Total HC[c] | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | lb/hr | kb/hr | lb/hr | kg/hr | lb/hr | kg/hr | lb/hr | kg/hr |
| TSCP700-4 | AiResearch | 770 | DC10, Airbus A300 | 523 | 237 | .6252 | 0.2836 | 4.655 | 2.112 | .1247 | .0566 |
| GTCP660-4 | AiResearch | 1180 | 747 | 1054 | 478 | 9.348 | 4.240 | 5.745 | 2.606 | .2384 | .1081 |
| GTCP85-129 | AiResearch | 270 | 737 | 270 | 122 | 2.454 | 1.113 | 1.547 | 0.714 | .0567 | .0257 |
| GTCP85-98CK | AiResearch | 270 | 727 | 270 | 122 | 2.033 | 0.922 | 1.553 | 0.704 | .0540 | .0245 |
| GTCP85-98D | AiResearch | 270 | DC9 | 297 | 135 | 1.641 | 0.744 | 1.783 | 0.809 | .0432 | .0196 |
| GTCP30 | AiResearch | 100 | Fairchild F27, Lockheed Jetstar | 106 | 48 | 0.558 | 0.253 | 0.393 | 0.178 | .0147 | .0067 |
| GTCP36-6 | AiResearch | 165 | Fairchild F28, Grumman GSII | 150 | 68 | 1.406 | 0.638 | 0.865 | 0.392 | .0611 | .0277 |
| ST6 | P&W Canada | 720 | L1011 | 439 | 199 | 0.454 | 0.206 | 3.982 | 1.806 | .0360 | .0163 |

[a]Ref. 35 quotes the following original sources:

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[b]Expressed as equivalent shaft horsepower

[c]Emission rates are expressed as mass of pollutant per hour at maximum power (shaft and bleed extraction). There is no duty cycle as such.

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## Appendix A

## COMPOSITION OF ORGANICS IN ENGINE EXHAUSTS – ADDITIONAL DATA

The data presented herein are reproduced verbatim from the report by Trijonis and Arledge (Ref. 6) discussed in Section 3 of this report. tables contain frequent departures from standard nomenclature. The reader should be cautious in applying the chemical constituent fractions and reactivity class fractions to real total "hydrocarbon" modal emission rates. In Ref. 6, the underlying assumptions and calculational basis for arriving at these data are not described. The reader should not conclude that the rather detailed tables imply a corresponding detail in our knowledge of volatile organic composition.

The piston engine data presented in Ref. 6 and reproduced here are derived from data for automotive engines without emission controls. The assumptions are: (a) reciprocating aircraft and automotive engines are fundamentally similar; (b) the fuel is similar; (c) aircraft engines lack emission controls; and (d) piston engine aircraft emissions make very much smaller contributions to photochemical smog than do turbine engines. Therefore, inaccurate data are more tolerable. These assumptions seem reasonable in the absence of hard data. Actual source tests might not be significantly more difficult than source tests on automobiles. We encountered no literature, however, suggesting that such tests had been done.

TABLE A-1. AVERAGE MOLECULAR WEIGHT OF THE ORGANICS EMITTED IN GAS TURBINE ENGINE EXHAUST, COMPLETE LTO CYCLE (REF. 6).

| CLASS I | | CLASS II | | CLASS III | | CLASS IV | | CLASS V | |
|---|---|---|---|---|---|---|---|---|---|
| $C_1$-$C_3$ paraffins | 30 | Mono-tert-alkyl ($C_{10}$) benzenes | 134 | $C_{4+}$-paraffins ($C_9$) | 128 | Prim-& sec-alkyl ($C_8$) benzenes | 106 | Aliphatic olefins | 112 |
| Acetylene | 25 | Cyclic ketones | | Cycloparaffins | | Dialkyl benzenes ($C_9$) | 120 | $\alpha$-methyl styrene | |
| Benzene | 78 | Tert-alkyl acetates | | Alkyl acetylenes | | Branched alkyl ketones | | Aliphatic alcenydes | 128 |
| Benzaldehyde | | 2-nitropropane | | Styrene | | Prim-& sec-alkyl alcohols | | Tri-& tetra-alkyl ($C_{11}$) benzenes | 148 |
| Acetone | | | | N-alkyl ketones | | Cellosolve acetate | | Unsaturated ketones | |
| Tert-alkyl alcohols | | | | Prim-& sec-alkyl acetates | | Partially halogenated olefins | | Diacetone alcohol | |
| Phenyl acetate | | | | N-methyl pyrrolidone | | | | Ethers | |
| Methyl benzoate | | | | N,N-dimethyl acetamide | | | | Cellosolves | |
| Ethyl amines | | | | | | | | | |
| Dimethyl formamide | | | | | | | | | |
| Methanol | | | | | | | | | |
| Perhalogenated hydrocarbons | | | | | | | | | |
| Partially halogenated paraffins | | | | | | | | | |

AVERAGE MOLECULAR WEIGHT 121

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TABLE A-2. ORGANIC EMISSIONS FROM GAS TURBINE ENGINES, COMPLETE LTO CYCLE* (REF. 6).

MOLE %

| CLASS I | | CLASS II | | CLASS III | | CLASS IV | | CLASS V | |
|---|---|---|---|---|---|---|---|---|---|
| $C_1$-$C_3$ paraffins | 7 | Mono-tert-alkyl benzenes | 4 | $C_{4+}$-paraffins | 38 | Prim-& sec-alkyl benzenes | 8 | Aliphatic olefins | 19 |
| Acetylene | 1 | Cyclic ketones | | Cycloparaffins | | Dialkyl benzenes | 8 | α-methyl styrene | |
| Benzene | 1 | Tert-alkyl acetates | | Alkyl acetylenes | | Branched alkyl ketones | | Aliphatic aldehydes | 10 |
| Benzaldehyde | | 2-nitropropane | | Styrene | | Prim-& sec-alkyl alcohols | | Tri-& tetra-alkyl benzenes | 4 |
| Acetone | | | | N-alkyl ketones | | Cellosolve acetate | | Unsaturated ketones | |
| Tert-alkyl alcohols | | | | Prim-& sec-alkyl acetates | | Partially halogenated olefins | | Diacetone alcohol | |
| Phenyl acetate | | | | N-methyl pyrrolidone | | | | Ethers | |
| Methyl benzoate | | | | N,N-dimethyl acetamide | | | | Cellosolves | |
| Ethyl amines | | | | | | | | | |
| Dimethyl formamide | | | | | | | | | |
| Methanol | | | | | | | | | |
| Perhalogenated hydrocarbons | | | | | | | | | |
| Partially halogenated paraffins | | | | | | | | | |
| TOTAL CLASS I | 9 | TOTAL CLASS II | 4 | TOTAL CLASS III | 38 | TOTAL CLASS IV | 16 | TOTAL CLASS V | 33 |

*For more detail, cf., Tables A-3, A-4 and A-5.

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TABLE A-3. ESTIMATED COMPOSITION OF THE ORGANICS EMITTED IN GAS TURBINE EXHAUST – TAXI-IDLE MODE (Ref. 6)

Mole %

| CLASS I | | CLASS II | | CLASS III | | CLASS IV | | CLASS V | |
|---|---|---|---|---|---|---|---|---|---|
| $C_1$-$C_3$ paraffins | 7 | Mono-tert-alkyl benzenes | 4 | $C_{4+}$-paraffins | 22 | Prim-& sec-alkyl benzenes | 16 | Aliphatic olefins | 20 |
| Acetylene | 1 | Cyclic ketones | | Cycloparaffins | | Dialkyl benzenes | 15 | $\alpha$-methyl styrene | |
| Benzene | 1 | Tert-alkyl acetates | | Alkyl acetylenes | | Branched alkyl ketones | | Aliphatic aldehydes | 10 |
| Benzaldehyde | | 2-nitropropane | | Styrene | | Prim-& sec-alkyl alcohols | | Tri-& tetra-alkyl benzenes | 4 |
| Acetone | | | | N-alkyl ketones | | Cellosolve acetate | | Unsaturated ketones | |
| Tert-alkyl alcohols | | | | Prim-& sec-alkyl acetates | | Partially halogenated olefins | | Diacetone alcohol | |
| Phenyl acetate | | | | N-methyl pyrrolidone | | | | Ethers | |
| Methyl benzoate | | | | N,N-dimethyl acetamide | | | | Cellosolves | |
| Ethyl amines | | | | | | | | | |
| Dimethyl formamide | | | | | | | | | |
| Methanol | | | | | | | | | |
| Perhalogenated hydrocarbons | | | | | | | | | |
| Partially halogenated paraffins | | | | | | | | | |
| TOTAL CLASS I | 9 | TOTAL CLASS II | 4 | TOTAL CLASS III | 22 | TOTAL CLASS IV | 31 | TOTAL CLASS V | 34 |

TABLE A-4. ESTIMATED COMPOSITION OF THE ORGANICS EMITTED IN GAS TURBINE EXHAUST – TAKEOFF MODE (Ref. 6)

MOLE %

| CLASS I | | CLASS II | | CLASS III | | CLASS IV | | CLASS V | |
|---|---|---|---|---|---|---|---|---|---|
| $C_1$-$C_3$ paraffins | 2 | Mono-tert-alkyl benzenes | 6 | $C_{4+}$-paraffins | 15 | Prim-& sec-alkyl benzenes | 8 | Aliphatic olefins | 20 |
| Acetylene | | Cyclic ketones | | Cycloparaffins | | Dialkyl benzenes | 13 | α-methyl styrene | |
| Benzene | | Tert-alkyl acetates | | Alkyl acetylenes | | Branched alkyl ketones | | Aliphatic aldehydes | 30 |
| Benzaldehyde | | 2-nitropropane | | Styrene | | Prim-& sec-alkyl alcohols | | Tri-& tetra-alkyl benzenes | 6 |
| Acetone | | | | N-alkyl ketones | | Cellosolve acetate | | Unsaturated ketones | |
| Tert-alkyl alcohols | | | | Prim-& sec-alkyl acetates | | Partially halogenated olefins | | Diacetone alcohol | |
| Phenyl acetate | | | | N-methyl pyrrolidone | | | | Ethers | |
| Methyl benzoate | | | | N,N-dimethyl acetamide | | | | Cellosolves | |
| Ethyl amines | | | | | | | | | |
| Dimethyl formamide | | | | | | | | | |
| Methanol | | | | | | | | | |
| Perhalogenated hydrocarbons | | | | | | | | | |
| Partially halogenated paraffins | | | | | | | | | |
| TOTAL CLASS I | 2 | TOTAL CLASS II | 6 | TOTAL CLASS III | 15 | TOTAL CLASS IV | 21 | TOTAL CLASS V | 56 |

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TABLE A-5. ESTIMATED COMPOSITION OF THE ORGANICS EMITTED IN GAS TURBINE EXHAUST – APPROACH MODE (REF. 6).

MOLE %

| CLASS I | | CLASS II | | CLASS III | | CLASS IV | | CLASS V | |
|---|---|---|---|---|---|---|---|---|---|
| $C_1$-$C_3$ paraffins | 1 | Mono-tert-alkyl benzenes | | $C_{4+}$-paraffins | 10 | Prim-& sec-alkyl benzenes | 9 | Aliphatic olefins | 10 |
| Acetylene | | Cyclic ketones | | Cycloparaffins | | Dialkyl benzenes | 9 | $\alpha$-methyl styrene | |
| Benzene | 1 | Tert-alkyl acetates | | Alkyl acetylenes | | Branched alkyl ketones | | Aliphatic aldehydes | 60 |
| Benzaldehyde | | 2-nitropropane | | Styrene | | Prim-& sec-alkyl alcohols | | Tri-& tetra-alkyl benzenes | |
| Acetone | | | | N-alkyl ketones | | Cellosolve acetate | | Unsaturated ketones | |
| Tert-alkyl alcohols | | | | Prim-& sec-alkyl acetates | | Partially halogenated olefins | | Diacetone alcohol | |
| Phenyl acetate | | | | N-methyl pyrrolidone | | | | Ethers | |
| Methyl benzoate | | | | N,N'-dimethyl acetamide | | | | Cellosolves | |
| Ethyl amines | | | | | | | | | |
| Dimethyl formamide | | | | | | | | | |
| Methanol | | | | | | | | | |
| Perhalogenated hydrocarbons | | | | | | | | | |
| Partially halogenated paraffins | | | | | | | | | |
| TOTAL CLASS I | 2 | TOTAL CLASS II | 0 | TOTAL CLASS III | 10 | TOTAL CLASS IV | 18 | TOTAL CLASS V | 70 |



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TABLE A-6. AVERAGE MOLECULAR WEIGHT OF THE ORGANICS EMITTED IN PISTON ENGINE AIRCRAFT EXHAUST (REF. 6).

| CLASS I | | CLASS II | | CLASS III | | CLASS IV | | CLASS V | |
|---|---|---|---|---|---|---|---|---|---|
| $C_1$-$C_3$ paraffins | 20 | Mono-tert-alkyl benzenes | | $C_{4+}$-paraffins | 97 | Prim-& sec-alkyl benzenes | 92 | Aliphatic olefins | 40 |
| Acetylene | 26 | Cyclic ketones | | Cycloparaffins | 110 | Dialkyl benzenes | 113 | $\alpha$-methyl styrene | |
| Benzene | 79 | Tert-alkyl acetates | | Alkyl acetylenes | | Branched alkyl ketones | | Aliphatic aldehydes | |
| Benzaldehyde | | 2-nitropropane | | Styrene | | Prim-& sec-alkyl alcohols | | Tri-& tetra-alkyl benzenes | 123 |
| Acetone | | | | N-alkyl ketones | | Cellosolve acetate | | Unsaturated ketones | |
| Tert-alkyl alcohols | | | | Prim-& sec-alkyl acetates | | Partially halogenated olefins | | Diacetone alcohol | |
| Phenyl acetate | | | | N-methyl pyrrolidone | | | | Ethers | |
| Methyl benzoate | | | | N,N-dimethyl acetamide | | | | Cellosolves | |
| Ethyl amines | | | | | | | | | |
| Dimethyl formamide | | | | | | | | | |
| Methanol | | | | | | | | | |
| Perhalogenated hydrocarbons | | | | | | | | | |
| Partially halogenated paraffins | | | | | | | | | |

AVERAGE MOLECULAR WEIGHT 56

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TABLE A-7. COMPOSITION OF THE ORGANICS EMITTED IN PISTON AIRCRAFT ENGINE EXHAUST (AS APPROXIMATED BY UNCONTROLLED AUTOMOTIVE EMISSIONS) (REF. 6).

Mole %

| CLASS I | | CLASS II | | CLASS III | | CLASS IV | | CLASS V | |
|---|---|---|---|---|---|---|---|---|---|
| $C_1$-$C_3$ paraffins | 20 | Mono-tert-alkyl benzenes | | $C_{4+}$-paraffins | 22 | Prim-& sec-alkyl benzenes | 6 | Aliphatic olefins | 31 |
| Acetylene | 12 | Cyclic ketones | | Cycloparaffins | 1 | Dialkyl benzenes | 4 | α-methyl styrene | |
| Benzene | 2 | Tert-alkyl acetates | | Alkyl acetylenes | | Branched alkyl ketones | | Aliphatic aldehydes | |
| Benzaldehyde | | 2-nitropropane | | Styrene | | Prim-& sec-alkyl alcohols | | Tri-& tetra-alkyl benzenes | 2 |
| Acetone | | | | N-alkyl ketones | | Cellosolve acetate | | Unsaturated ketones | |
| Tert-alkyl alcohols | | | | Prim-& sec-alkyl acetates | | Partially halogenated olefins | | Diacetone alcohol | |
| Phenyl acetate | | | | N-methyl pyrrolidone | | | | Ethers | |
| Methyl benzoate | | | | N,N-dimethyl acetamide | | | | Cellosolves | |
| Ethyl amines | | | | | | | | | |
| Dimethyl formamide | | | | | | | | | |
| Methanol | | | | | | | | | |
| Perhalogenated hydrocarbons | | | | | | | | | |
| Partially halogenated paraffins | | | | | | | | | |
| TOTAL CLASS I | 34 | TOTAL CLASS II | 0 | TOTAL CLASS III | 23 | TOTAL CLASS IV | 10 | TOTAL CLASS V | 33 |

Appendix B

# SUGGESTED REVISION OF SECTION 3.2.1 "AIRCRAFT" OF AP-42

Material appearing in this appendix represents a condensation of the data and discussion presented in the body of this document. It is intended to be self-contained, since it is proposed for use in AP-42 with changes in page, paragraph, and table numbers only. Consequently, this appendix contains its own references.

## B.1 AIRCRAFT

### B.1.1 General

Aircraft engines are of two major categories: reciprocating (piston) and gas turbine.

The basic element in the aircraft piston engine is the combustion chamber, or cylinder, in which mixtures of fuel and air are burned and from which energy is extracted through a piston and crank mechanism that drives a propeller. The majority of aircraft piston engines have two or more cylinders and are generally classified according to their cylinder arrangement – either "opposed" or "radial." Opposed engines are installed in most light or utility aircraft; radial engines are used mainly in large transport aircraft. Almost no single-row inline or V-engines are used in current aircraft.

The gas turbine engine in general consists of a compressor, a combustion chamber, and a turbine. Air entering the forward end of the engine is compressed and then heated by burning fuel in the combustion chamber. The major portion of the energy in the heated air stream is used for aircraft propulsion. Part of the energy is expended in driving the turbine, which in turn drives the compressor. Turbofan and turboprop or turboshaft engines use energy from the turbine for propulsion; turbojet engines use only the expanding exhaust stream for propulsion. The terms "propjet" and "fanjet" are sometimes used for turboprop and turbofan, respectively.

The aircraft in the following tables include only those believed to be significant now, or those which will become significant shortly due to procurements over the next few years.

Few piston engine aircraft data appear here. Military fixed wing piston aircraft, even among trainers, are being phased out. One piston

engine helicopter, the TH-55A "Osage" sees extensive use at one training base at Ft. Rucker, Ala. (EPA Region IV); however, engine emissions data are not available. Most civil piston engine aircraft are in general aviation service.

The fact that a particular aircraft is not listed in the following tables does not imply that emission factors cannot be calculated. It is the engine emissions and the time-in-mode category which determine emissions. If these are known, emission factors can be calculated in the same way that the following tables were developed.

The aircraft classification system used is listed in Table B.1-1 and B.1-2. Aircraft have been divided into sub-classes depending on the kind of aircraft and the most commonly used engine for that class. Jumbo jets normally have approximately 40,000 lb maximum thrust per engine, and medium-range jets have about 14,000 lb maximum thrust per engine. Small piston engines develop less than 500 horsepower.

### B.1.2 The Landing Takeoff Cycle and Times in Mode

A landing take-off cycle (LTO cycle) incorporates all of the normal flight and ground operational modes (at their respective times-in-mode, TIMs), including: descent/approach from approximately 3000 ft (914 m) above ground level (AGL), touchdown, landing run, taxi-in, idle and shut-down, start-up and idle, check out, taxi-out, takeoff, and climbout to 3000 ft (914 m) AGL.

In order to make the available data manageable, and to facilitate comparisons, all of these operations are conventionally grouped into five standardized modes: approach, taxi/idle (in), taxi/idle (out), takeoff and climbout. There are exceptions. The supersonic transport (SST) has a descent mode preceding approach. Helicopters omit the takeoff mode. Training exercises involve "touch and go" practice. These omit the taxi/idle modes, and the maximum altitude reached is much lower. Hence the duration (TIM) of the approach and climbout modes will be shorter.

Each class of aircraft has its own typical LTO cycle (set of TIMs). For major classes of aircraft, these are shown in Tables B.1-3 and B.1-4. The TIM data appearing in those tables should be used for guidance only and in the absence of specific observations. The military data are inappropriate to primary training. The civil data refer to large, congested fields at times of heavy activity.

All of the data assume a 3000 ft AGL inversion height, an average U.S. mixing depth. This may be inappropriate at specific localities and times, for which site-specific and time-specific inversion height data should be sought. Aircraft emissions of concern here are those released to the atmosphere below the inversion. If local conditions suggest higher or lower inversions, the duration (TIM) of the approach and climbout modes must be adjusted correspondingly.

TABLE B.1-1 CIVIL AIRCRAFT CLASSIFICATION[a]

| Aircraft | Engines[b] | | | |
|---|---|---|---|---|
| | No. | Mfg. | Type | Model-Series |
| **Supersonic Transport** | | | | |
| BAC/Aerospatiale Concorde | 4 | RP | TJ | Olymp. 593-610 |
| **Short, Medium, Long Range and Jumbo Jets** | | | | |
| BAC 111-400 | 2 | RR | TF | Spey 511 |
| Boeing 707-320B | 4 | P&W | TF | JT3D-7 |
| Boeing 727-200 | 3 | P&W | TF | JT8D-17 |
| Boeing 737-200 | 2 | P&W | TF | JT8D-17 |
| Boeing 747-200B | 4 | P&W | TF | JT9D-7 |
| Boeing 747-200B | 4 | P&W | TF | JT9D-70 |
| Boeing 747-200B | 4 | RR | TF | RB211-524 |
| Lockheed L1011-200 | 3 | RR | TF | RB211-524 |
| Lockheed L1011-100 | 3 | RR | TF | RB211-22B |
| McDonnell-Douglas DC8-63 | 4 | P&W | TF | JT3D-7 |
| McDonnell-Douglas DC9-50 | 2 | P&W | TF | JT8D-17 |
| McDonnell-Douglas DC10-30 | 3 | GE | TF | CF6-50C |
| **Air Carrier Turboprops – Commuter, Feeder Line and Freighters** | | | | |
| Beech 99 | 2 | PWC | TP | PT6A-28 |
| GD/Convair 580 | 2 | All | TP | 501 |
| DeHavilland Twin Otter | 2 | PWC | TP | PT6A-27 |
| Fairchild F27 and FH227 | 2 | RR | TP | R. Da. 7 |
| Grumman Goose | 2 | PWC | TP | PT6A-27 |
| Lockheed L188 Electra | 4 | All | TP | 501 |
| Lockheed L100 Hercules | 4 | All | TP | 501 |
| Swearingen Metro-2 | 2 | GA | TP | TPE 331-3 |
| **Business Jets** | | | | |
| Cessna Citation | 2 | P&W | TF | JT15D-1 |
| Dassault Falcon 20 | 2 | GE | TF | CF700-2D |
| Gates Learjet 24D | 2 | GE | TJ | CJ610-6 |
| Gates Learjet 35, 36 | 2 | GE | TF | TPE 731-2 |
| Rockwell International Shoreliner 75A | 2 | GE | TF | CF 700 |
| **Business Turboprops (EPA Class P2)** | | | | |
| Beech B99 Airliner | 2 | PWC | TP | PT6A-27 |
| DeHavilland Twin Otter | 2 | PWC | TP | PT6A-27 |
| Shorts Skyvan-3 | 2 | GA | TP | TPE-331-2 |
| Swearingen Merlin IIIA | 2 | GA | TP | TPE-331-3 |
| **General Aviation Piston (FPA Class P1)** | | | | |
| Cessna 150 | 1 | Con | O | O-200 |
| Piper Warrior | 1 | Lyc | O | O-320 |
| Cessna Pressurized Skymaster | 2 | Con | O | TS10-360C |
| Piper Navajo Chieftain | 2 | Lyn | O | T10-540 |

[a] References 1, 2

[b] Abbreviations: TJ – turbojet, TF – turbofan, TP – turboprop; R – reciprocating piston; O – opposed piston. All – Detroit Diesel Allison Division of General Motors; Con – Teledyne/Continental; GA – Garrett AiResearch; GE – General Electric; Lyc – Avco/Lycoming; P&W – Pratt & Whitney; PWC – Pratt & Whitney Aircraft of Canada; RR – Rolls Royce.

## TABLE B.1-2. MILITARY AIRCRAFT CLASSIFICATIONS[a]

| Aircraft Mission (Class) | DOD Designation | Popular Name | Manufacturer[b] | Service | Power Plant | | |
|---|---|---|---|---|---|---|---|
| | | | | | No. & Type[c] | Mfg.[b] | Designation |
| Combat | A-4 | Skyhawk | McD-Doug | USN, USMC | 1 TJ | P&W | J52, J65 |
| | A-7 | Corsair 2 | Vought | USN | 1 TF | All, P&W | TF41, TF30 |
| | F-4 | Phantom 2 | McD-Doug | USAF, USN | 2 TJ | GE | J79 |
| | F-5 | Freedom Fighter (Tiger 2) | Northrop | USAF | 2 TJ | GE | J85 |
| | F-14 | Tomcat | Grumman | USN | 2 TF | P&W | TF30, F401 |
| | F-15A | Eagle | McD-Doug | USAF | 2 TF | P&W | F100 |
| | F-16 | -------- | GD/FW | USAF | 1 TF | P&W | F100 |
| Bomber | B-52 | Stratofortress | Boeing | USAF | 8 TJ, TF | P&W | J57, TF33 |
| Transport Patrol/Antisub | C-5A | Galaxy | GELAC | USAF | 4 TF | GE | TF39 |
| | C-130 | Hercules | GELAC | USAF, USN, USCG | 4 TP | All | T56 |
| | KC-135 | Stratotanker | Boeing | USAF | 4 TJ | P&W | J57 |
| | C-141 | Starlifter | GELAC | USAF | 4 TF | P&W | TF33 |
| | P-3C | Orion | CALAC | USN | 4 TP | All | T56 |
| | S-3A | Viking | CALAC | USN | 2 TF | GE | TF34 |
| Trainer | T-34C | Turbo Mentor | Beech | USN | 1 TP | PWC | PT6A |
| | T-38 | Talon | Northrop | USAF | 2 TJ | GE | J85 |
| Helicopters | UH-1H | Iroquois ("Huey") | Bell Heli | USA, USN | 1 TS | Lyc, GE | T53, T58 |
| | HH-3 | Sea King ("Jolly Green Giant") | Sikorsky | USAF, USN, USCG | 2 TS | GE | T58 |
| | CH-47 | Chinook | Booeing Vertol | USA | 2 TS | Lyc | T55 |

[a] Ref. 1.

[b] Abbreviations: All – Detroit Diesel Allison Division of General Motors; CALAC – Lockheed-California; GD/FW – General Dynamics, Ft. Worth; GE – General Electric; GELAC – Lockheed-Georgia; Lyc – Lycoming; McD-Doug – McDonnell Douglas; P&W – Pratt & Whitney; PWC – Pratt & Whitney Aircraft of Canada.

[c] TJ – Turbojet; TF – Turbofan; TP – Turboprop; TS – Turboshaft.

TABLE B.1-3. TYPICAL TIMES-IN-MODE FOR CIVIL LANDING-TAKEOFF CYCLES AT A LARGE, CONGESTED METROPOLITAN AIRPORT[a]

| Mode | Time-In-Mode (Minutes) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Air Carrier | | | | General Aviation | | | | Helicopter |
| | Jumbo Jet[b] | Long Range Jet[b] | Medium Range Jet[b] | Turboprop[c] | Piston Transport | Business Jet | Turboprop[c] | Piston[d] | |
| Taxi/Idle (Out) | 19.0 | 19.0 | 19.0 | 19.0 | 6.5 | 6.5 | 19.0 | 12.0 | 3.5 |
| Takeoff | 0.7 | 0.7 | 0.7 | 0.5 | 0.6 | 0.4 | 0.5 | 0.3 | — |
| Climbout | 2.2 | 2.2 | 2.2 | 2.5 | 5.0 | 0.5 | 2.5 | 4.98 | 6.5 |
| Approach | 4.0 | 4.0 | 4.0 | 4.5 | 4.6 | 1.6 | 4.5 | 6.0 | 6.5 |
| Taxi/Idle (In) | 7.0 | 7.0 | 7.0 | 7.0 | 6.5 | 6.5 | 7.0 | 4.0 | 3.5 |
| Total | 32.9 | 32.9 | 32.9 | 33.5 | 23.2 | 15.5 | 33.5 | 27.28 | 20.0 |

[a] Ref. 3.

[b] Same times as EPA classes T2, T3, T4. See footnote b, Table B.1-5.

[c] Same times as EPA classes T1 and P2. See footnote b, Table B.1-5.

[d] Same times as EPA class P1. See footnote b, Table B.1-5.

TABLE B.1-4. TIMES-IN-MODE DURING MILITARY CYCLES[a]

| Mode | Time-in-Mode (Minutes) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Combat[b] | | Turbine Trainers | | | Turbine Transport[c] | | KC-135 & B-52 | Military Piston (All) | Military Helicopter (All) |
| | USAF | USN | USAF T-38 | USAF Other | USN | USAF | USN[d] | | | |
| Code | 1 | 2 | 3 | 4 | 2 | 5 | 6 | 7 | 8 | 9 |
| Taxi/Idle (Out) | 18.5 | 6.5 | 12.8 | 6.8 | 6.5 | 9.2 | 19.0 | 32.8 | 6.5 | 8.0 |
| Takeoff | 0.4 | 0.4 | 0.4 | 0.5 | 0.4 | 0.4 | 0.5 | 0.7 | 0.6 | — |
| Climbout | 0.8 | 0.5 | 0.9 | 1.4 | 0.5 | 1.2 | 2.5 | 1.6 | 5.0 | 6.8 |
| Approach | 3.5 | 1.6 | 3.8 | 4.0 | 1.6 | 5.1 | 4.5 | 5.2 | 4.6 | 6.8 |
| Taxi/Idle (In) | 11.3 | 6.5 | 6.4 | 4.4 | 6.5 | 6.7 | 7.0 | 14.9 | 6.5 | 7.0 |
| Total | 34.5 | 15.5 | 24.3 | 17.1 | 15.5 | 22.6 | 33.5 | 55.2 | 23.2 | 28.6 |

[a] Reference 1.

[b] Includes fighters and attack aircraft only.

[c] Includes transport, cargo, observation, patrol, antisubmarine, early warning, and utility; i.e., all turbine aircraft not specifically listed in other columns.

[d] Same as EPA specified class P2 for civil turboprops.

A more detailed discussion of the assumptions and limitations implicit in these data appears in Ref. 1.

Emission factors in Tables B.1-9 and B.1-10 were determined using the times-in-mode presented in Tables B.1-3 and B.1-4, and generally for the engine power settings given in Tables B.1-5 and B.1-6.

B.1-3 Modal Emission Rates and Emission Factors per LTO Cycle

The first step in the calculation of aircraft emission factors is the development of a set of modal emission rates. These represent the quantity of pollutant released per unit time in each of the standard modes. Each mode is characterized by an engine power setting (Tables B.1-5 and B.1-6) and a fuel rate, the quantity of fuel combusted per unit time.

The procedure for calculation of aircraft emission factors per LTO cycle starting with engine modal emission rates, follows:

1. For a specific aircraft, determine the number and model of engines, using for example, Table B.1-1 or B.1-2.
2. Using Table B.1-7 or B.1-8, locate the appropriate engine data, and prepare a list of modal emission rates

$$\left(\frac{\Delta e}{\Delta t}\right)_{m,p}$$

for each mode m and pollutant p.

3. Using known military assignment and mission or civil aircraft type and application, use Table B.1-3 or B.1-4 to select an appropriate set of times-in-mode $(TIM)_m$.
4. For each mode m and pollutant p, multiply the modal emission rate and TIM data for each mode and sum over all modes. This will yield an emission factor per engine, which must be multiplied by the number of engines, N, to produce the emission factor per LTO cycle, $E_p$, for an aircraft:

$$E_p = N \sum_m \left(\frac{\Delta e}{\Delta t}\right)_{m,p} \cdot (TIM)_m$$

This calculation can be set up easily on a hand calculator with one storage location, using a conveniently laid out work sheet.

Emission factors calculated in exactly this way are presented in Tables B.1-9 and B.1-10.

TABLE B.1-5. ENGINE POWER SETTINGS FOR THE STANDARD EPA LTO CYCLE FOR COMMERCIAL ENGINES[a]

| Mode | Power Setting (percent thrust or horsepower) | | | |
|---|---|---|---|---|
| | Class T1, P2[b] | Class T2, T3, T4[b] | Class P1[b] | Helicopter |
| Taxi/Idle (out) | Idle | Idle | Idle | |
| Takeoff | 100% | 100% | 100% | |
| Climbout | 90% | 85% | 75%-100% | Undefined |
| Approach | 30% | 30% | 40% | |
| Taxi/Idle (in) | Idle | Idle | Idle | |

[a]Refs. 1, 3.

[b]As defined by EPA (Ref. 3).

"Class T1" means all aircraft turbofan or turbojet engines except engines of Class T5 of rated power less than 8,000 pounds thrust.

"Class T2" means all turbofan or turbojet aircraft engines except engines of Class T3, T4, and T5 of rated power of 8,000 pounds thrust or greater.

"Class T3" means all aircraft gas turbine engines of the JT3D model family.

"Class T4" means all aircraft gas turbine engines of the JT8D model family.

"Class T5" means all aircraft gas turbine engines employed for propulsion of aircraft designed to operate at supersonic flight speeds.

"Class P1" means all aircraft piston engines, except radial engines.

"Class P2" means all aircraft turboprop engines.

TABLE B.1-6. ENGINE POWER SETTINGS FOR A TYPICAL MILITARY CYCLE[a]

| Mode | Power Setting (percent thrust or horsepower) | | | |
|---|---|---|---|---|
| | Military Transport | Military Jet | Military Piston | Military Helicopter |
| Taxi/Idle (out) | Idle | Idle | 5-10% | Idle |
| Takeoff | Military | Military or Afterburner | 100% | — |
| Climbout | 90-100% | Military | 75% | 60-75% |
| Approach | 30% | 84-86% | 30% | 45-50% |
| Taxi/Idle (in) | Idle | Idle | 5-10% | Idle |

[a]Ref. 1.

TABLE B.1-7. MODAL EMISSION RATES – CIVIL AIRCRAFT ENGINES[a]

| Model-Series Mfg.[b] Type[b] | Mode | Fuel Rate | | CO | | $NO_x$[c] | | Total HC[d] | | $SO_x$[e] | | Solid Particulates[f] | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | lb/hr | kg/hr | lb/hr | kg/hr | lb/hr | kg/hr | lb/hr | kg/hr | lb/hr | kg/hr | lb/hr | kg/hr |
| 250B17B | Idle | 63 | 28.58 | 6.13 | 2.78 | 0.09 | 0.041 | 1.27 | 0.576 | 0.06 | 0.03 | | |
| All. TP | Takeoff | 265 | 120.2 | 2.07 | 0.939 | 1.75 | 0.794 | 0.07 | 0.032 | 0.27 | 0.12 | | |
| | Climbout | 245 | 111.1 | 2.21 | 1.00 | 1.46 | 0.662 | 0.09 | 0.041 | 0.25 | 0.11 | | |
| | Approach | 85 | 38.56 | 4.13 | 1.87 | 0.19 | 0.086 | 0.44 | 0.200 | 0.09 | 0.04 | | |
| 501D22A | Idle | 610 | 276.7 | 26.60 | 12.07 | 2.15 | 0.975 | 10.74 | 4.87 | 0.61 | 0.28 | | |
| All. TP | Takeoff | 2376 | 1078 | 4.85 | 2.20 | 21.10 | 9.57 | 0.67 | 0.304 | 2.38 | 1.08 | | |
| | Climbout | 2198 | 997 | 4.53 | 2.05 | 20.27 | 9.19 | 1.96 | 0.889 | 2.20 | 1.00 | | |
| | Approach | 1140 | 517.1 | 5.81 | 2.64 | 8.54 | 3.87 | 2.23 | 1.01 | 1.14 | 0.52 | | |
| TPE 331-3 | Idle | 112.0 | 50.8 | 6.89 | 3.12 | 0.320 | 0.145 | 8.86 | 4.02 | 0.11 | 0.05 | 0.3[g] | 0.14[g] |
| GA TP | Takeoff | 458.0 | 207.7 | 0.350 | 0.159 | 5.66 | 2.57 | 0.050 | 0.023 | 0.46 | 0.21 | 0.8 | 0.36 |
| | Climbout | 409.0 | 185.5 | 0.400 | 0.181 | 4.85 | 2.20 | 0.060 | 0.027 | 0.41 | 0.19 | 0.6 | 0.27 |
| | Approach | 250.0 | 113.4 | 1.74 | 0.789 | 2.48 | 1.12 | 0.160 | 0.073 | 0.25 | 0.11 | 0.6 | 0.27 |
| TPE331-2 | Idle | 105.0 | 47.6 | 6.73 | 3.05 | 0.27 | 0.22 | 9.58 | 4.34 | 0.11 | 0.05 | (Assume 331-3 | |
| GA TP | Takeoff | 405.0 | 183.7 | 0.38 | 0.172 | 4.14 | 1.88 | 0.16 | 0.072 | 0.41 | 0.18 | data) | |
| | Climbout | 372.0 | 168.7 | 0.51 | 0.231 | 3.69 | 1.67 | 0.15 | 0.068 | 0.37 | 0.17 | | |
| | Approach | 220.0 | 99.8 | 3.65 | 1.66 | 1.82 | 0.826 | 0.59 | 0.268 | 0.22 | 0.10 | | |
| TPE 731-2 | Idle | 181.0 | 82.1 | 11.11 | 5.04 | 0.54 | 0.245 | 4.05 | 1.84 | 0.18 | 0.08 | | |
| GA TF | Takeoff | 1552.0 | 704.0 | 1.86 | 0.844 | 29.8 | 13.52 | 0.14 | 0.064 | 1.55 | 0.70 | | |
| | Climbout | 1385.0 | 628.2 | 1.80 | 0.816 | 23.68 | 10.74 | 0.12 | 0.054 | 1.39 | 0.63 | | |
| | Approach | 521.0 | 236.3 | 9.53 | 4.32 | 3.59 | 1.63 | 1.51 | 0.685 | 0.52 | 0.24 | | |
| CJ 610-2C | Idle | 510.0 | 231.3 | 79.05 | 35.86 | 0.46 | 0.209 | 9.18 | 4.16 | 0.51 | 0.23 | | |
| GE TJ | Takeoff | 2780.0 | 1261.0 | 75.06 | 34.05 | 11.68 | 5.30 | 0.28 | 0.127 | 2.78 | 1.26 | | |
| | Climbout | 2430.0 | 1102.0 | 65.61 | 29.76 | 8.99 | 4.08 | 0.49 | 0.222 | 2.43 | 1.10 | | |
| | Approach | 1025.0 | 464.9 | 90.20 | 40.91 | 1.54 | 0.698 | 2.77 | 1.26 | 1.03 | 0.46 | | |
| CF700-2D | Idle | 460 | 208.7 | 71.30 | 32.34 | 0.41 | 0.186 | 8.28 | 3.76 | 0.46 | 0.21 | | |
| GE TF | Takeoff | 2607 | 1182 | 57.35 | 26.01 | 14.60 | 6.62 | 0.26 | 0.118 | 2.61 | 1.18 | | |
| | Climbout | 2322 | 1053 | 58.05 | 26.33 | 9.98 | 4.53 | 0.23 | 0.104 | 2.32 | 1.05 | | |
| | Approach | 919 | 416.9 | 56.98 | 25.85 | 1.65 | 0.748 | 1.29 | 0.585 | 0.92 | 0.42 | | |
| CF6-6D | Idle | 1063 | 482.2 | 65.06 | 29.51 | 4.88 | 2.21 | 21.79 | 9.88 | 1.06 | 0.48 | 0.04[g] | 0.02[g] |
| GE TF | Takeoff | 13750 | 6237 | 8.25 | 3.74 | 467.5 | 212.1 | 8.25 | 3.74 | 13.75 | 6.24 | 0.54 | 0.24 |
| | Climbout | 11329 | 5139 | 6.80 | 3.03 | 309.2 | 140.2 | 6.80 | 3.08 | 11.33 | 5.14 | 0.54 | 0.24 |
| | Approach | 3864 | 1753 | 23.18 | 10.51 | 41.54 | 18.84 | 6.96 | 3.16 | 3.86 | 1.75 | 0.44 | 0.20 |
| CF6-50C | Idle | 1206 | 547 | 88.04 | 39.93 | 3.02 | 1.37 | 36.18 | 16.41 | 1.21 | 0.55 | (Assume CF6-6D | |
| GE TF | Takeoff | 18900 | 8573 | 0.38 | 0.172 | 670.95 | 304.3 | 0.19 | 0.086 | 18.90 | 8.57 | data) | |
| | Climbout | 15622 | 7104 | 4.70 | 2.13 | 462.0 | 209.6 | 0.16 | 0.073 | 15.62 | 7.10 | | |
| | Approach | 5280 | 2395 | 22.70 | 10.30 | 52.8 | 23.95 | 0.05 | 0.023 | 5.28 | 2.40 | | |

TABLE B.1-7 (CONTINUED)

| Model-Series Mfg.[b] Type[b] | Mode | Fuel Rate | | CO | | $NO_x$[c] | | Total HC[d] | | $SO_x$[e] | | Solid Particulates[f] | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | lb/hr | kg/hr | lb/hr | kg/hr | lb/hr | kg/hr | lb/hr | kg/hr | lb/hr | kg/hr | lb/hr | kg/hr |
| JT3D-7 | Idle | 1013 | 459.5 | 140.8 | 63.87 | 2.23 | 1.01 | 124.6 | 56.52 | 1.01 | 0.46 | 0.45[g] | 0.20[g] |
| P&W TF | Takeoff | 9956 | 4516 | 8.96 | 4.06 | 126.4 | 57.34 | 4.98 | 2.26 | 9.96 | 4.52 | 8.25 | 3.7 |
| | Climbout | 8188 | 3714 | 15.56 | 7.06 | 78.6 | 35.65 | 3.28 | 1.49 | 8.19 | 3.71 | 8.5 | 3.9 |
| | Approach | 3084 | 1399 | 60.14 | 27.28 | 16.35 | 7.42 | 6.48 | 2.94 | 3.08 | 1.40 | 8.0 | 3.6 |
| JT8D-17 | Idle | 1150 | 521.6 | 39.10 | 17.74 | 3.91 | 1.77 | 10.10 | 4.58 | 1.15 | 0.52 | 0.36[g, h] | 0.16[g, h] |
| P&W TF | Takeoff | 9980 | 4527 | 6.99 | 3.17 | 202.6 | 91.90 | .50 | 0.227 | 9.98 | 4.53 | 3.7 | 1.7 |
| | Climbout | 7910 | 3588 | 7.91 | 3.59 | 123.4 | 55.97 | .40 | 0.181 | 7.91 | 3.59 | 2.6 | 1.2 |
| | Approach | 2810 | 1275 | 20.23 | 9.18 | 19.39 | 8.80 | 1.41 | 0.640 | 2.81 | 1.28 | 1.5 | 0.68 |
| JT9D-7 | Idle | 1849 | 838.7 | 142.4 | 64.59 | 5.73 | 2.60 | 55.10 | 24.99 | 1.85 | 0.84 | 2.2[f] | 1.0 |
| P&W TF | Takeoff | 16142 | 7322 | 3.23 | 1.47 | 474.6 | 215.3 | 0.81 | 0.367 | 16.14 | 7.32 | 3.75 | 1.7 |
| | Climbout | 13193 | 5984 | 6.60 | 2.99 | 282.3 | 128.0 | 1.32 | 0.599 | 13.19 | 5.98 | 4.0 | 1.8 |
| | Approach | 4648 | 2108 | 44.62 | 20.24 | 36.25 | 16.44 | 4.65 | 2.11 | 4.65 | 2.11 | 2.3 | 1.0 |
| JT9D-70 | Idle | 1800 | 816.5 | 61.20 | 27.76 | 5.76 | 2.61 | 12.24 | 0.55 | 1.80 | 0.82 | | |
| P&W TF | Takeoff | 19380 | 8791 | 3.88 | 1.76 | 600.8 | 272.5 | 2.91 | 1.32 | 19.38 | 8.79 | (assume JT9D-7 data) | |
| | Climbout | 15980 | 7248 | 4.79 | 2.17 | 386.7 | 175.4 | 2.40 | 1.09 | 15.98 | 7.25 | | |
| | Approach | 5850 | 2654 | 7.61 | 3.45 | 47.39 | 21.50 | 2.63 | 1.19 | 5.85 | 2.65 | | |
| JT15D-1 | Idle | 215 | 97.52 | 19.46 | 8.83 | 0.54 | 0.245 | 7.48 | 3.39 | 0.22 | 0.10 | | |
| PWC TF | Takeoff | 1405 | 637.3 | 1.41 | 0.640 | 14.19 | 6.44 | 0 | 0 | 1.41 | 0.64 | | |
| | Climbout | 1247 | 565.6 | 1.25 | 0.567 | 11.35 | 5.15 | 0 | 0 | 1.25 | 0.57 | | |
| | Approach | 481 | 218.2 | 11.45 | 5.19 | 2.45 | 1.11 | 1.59 | 0.721 | 0.48 | 0.22 | | |
| PT6A-27 | Idle | 115 | 52.16 | 7.36 | 3.34 | 0.28 | 0.127 | 5.77 | 2.62 | 0.12 | 0.05 | | |
| PWC TP | Takeoff | 425 | 192.8 | 0.43 | 0.195 | 3.32 | 1.51 | 0 | 0 | 0.43 | 0.19 | | |
| | Climbout | 400 | 181.4 | 0.48 | 0.218 | 2.80 | 1.27 | 0 | 0 | 0.40 | 0.18 | | |
| | Approach | 215 | 97.52 | 4.95 | 2.24 | 1.80 | 0.816 | 0.47 | 0.213 | 0.22 | 0.10 | | |
| PT6A-41 | Idle | 147 | 66.63 | 16.95 | 7.69 | 0.29 | 0.132 | 14.94 | 6.78 | 0.15 | 0.07 | | |
| PWC TP | Takeoff | 510 | 231.3 | 2.60 | 1.18 | 4.07 | 1.85 | 0.89 | 0.404 | 0.51 | 0.23 | | |
| | Climbout | 473 | 214.6 | 3.07 | 1.39 | 3.58 | 1.62 | 0.96 | 0.435 | 0.47 | 0.21 | | |
| | Approach | 273 | 123.8 | 9.50 | 4.31 | 1.27 | 0.576 | 6.20 | 2.81 | 0.27 | 0.12 | | |
| Spey 555-15[i] | Idle | 915 | 415 | 83.2 | 37.7 | 1.6 | 0.7 | 86.0 | 43.5 | 0.92 | 0.42 | | |
| RR TF | Takeoff | 5734 | 2600 | 6.5 | 3.0 | 109.2 | 49.5 | 29.5 | 13.4 | 5.73 | 2.60 | | |
| | Climbout | 4677 | 2121 | 0.0 | 0.0 | 68.7 | 31.2 | 2.5 | 1.1 | 4.68 | 2.12 | | |
| | Approach | 1744 | 791 | 34.8 | 15.8 | 10.2 | 4.6 | 14.3 | 6.5 | 1.74 | 0.79 | | |
| Spey MK511[g, i] | Idle | 946 | 429.1 | 104.4 | 47.36 | 0.785 | 0.356 | 80.03 | 36.30 | 0.95 | 0.43 | 0.17 | 0.077 |
| RR TF | Takeoff | 7057 | 3201 | 16.16 | 7.33 | 156.7 | 71.08 | 13.97 | 6.34 | 7.06 | 3.20 | 16.0 | 7.3 |
| | Climbout | 5752 | 2609 | 0.0 | 0.0 | 116.8 | 52.98 | 0.0 | 0.0 | 5.75 | 2.61 | 10.0 | 4.5 |
| | Approach | 2204 | 999.7 | 48.71 | 22.09 | 16.00 | 7.26 | 20.56 | 9.33 | 2.20 | 1.00 | 1.5 | 0.68 |
| M45H-01[i] | Idle | 366 | 166.0 | 55.63 | 25.23 | 0.622 | 0.282 | 11.53 | 5.23 | 0.37 | 0.17 | | |
| RR (Bristol) | Takeoff | 3590 | 1628 | 7.18 | 3.26 | 32.31 | 14.66 | 0.718 | 0.326 | 3.59 | 1.62 | | |
| TF | Climbout | 3160 | 1433 | 9.48 | 4.30 | 25.28 | 11.47 | 0.632 | 0.287 | 3.16 | 1.43 | | |
| | Approach | 1067 | 484.0 | 53.56 | 24.29 | 3.57 | 1.62 | 6.61 | 3.00 | 1.07 | 0.48 | | |

TABLE B.1-7 (CONTINUED)

| Model-Series Mfg[b] Type[b] | Mode | Fuel Rate lb/hr | Fuel Rate kg/hr | CO lb/hr | CO kg/hr | $NO_x$[c] lb/hr | $NO_x$[c] kg/hr | Total HC[d] lb/hr | Total HC[d] kg/hr | $SO_x$[e] lb/hr | $SO_x$[e] kg/hr | Solid Particulates[f] lb/hr | Solid Particulates[f] kg/hr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RB-211-22B[i] RR TF | Idle | 1718 | 779.3 | 137.6 | 64.42 | 5.31 | 2.41 | 100.1 | 45.36 | 1.72 | 0.78 | | |
| | Takeoff | 14791 | 6709 | 5.62 | 2.55 | 504.1 | 228.7 | 29.14 | 13.22 | 14.79 | 6.71 | | |
| | Climbout | 12205 | 5536 | 14.89 | 6.75 | 301.9 | 136.9 | 8.30 | 3.76 | 12.21 | 5.54 | | |
| | Approach | 4376 | 1985 | 93.78 | 42.54 | 32.26 | 14.63 | 32.16 | 14.59 | 4.38 | 1.99 | | |
| RB-211-524[i] RR TF | Idle | 1769 | 802.4 | 35.91 | 16.29 | 4.74 | 2.15 | 5.43 | 2.46 | 1.77 | 0.80 | | |
| | Takeoff | 17849 | 8096 | 7.32 | 3.32 | 660.4 | 299.6 | 1.96 | 0.889 | 17.85 | 8.10 | | |
| | Climbout | 14688 | 6662 | 7.34 | 3.33 | 470.0 | 213.2 | 2.50 | 1.13 | 14.69 | 6.67 | | |
| | Approach | 5450 | 2472 | 11.72 | 5.32 | 62.89 | 28.53 | 0.545 | 0.247 | 5.45 | 2.47 | | |
| RB-401-06[i] RR TF | Idle | 330 | 149.7 | 10.07 | 4.57 | 0.825 | 0.374 | 0.924 | 0.419 | 0.33 | 0.15 | | |
| | Takeoff | 2400 | 1089 | 2.40 | 1.09 | 30.0 | 13.61 | 0.120 | 0.054 | 2.40 | 1.09 | | |
| | Climbout | 2130 | 966.2 | 2.77 | 1.26 | 24.07 | 10.92 | 0.107 | 0.049 | 2.13 | 0.97 | | |
| | Approach | 775 | 351.5 | 5.04 | 2.29 | 3.88 | 1.76 | 0.155 | 0.070 | 0.78 | 0.35 | | |
| Dart RDa7[i] RR TP | Idle | 411 | 186.4 | 37.61 | 17.06 | 0.292 | 0.132 | 25.52 | 11.58 | 0.41 | 0.19 | | |
| | Takeoff | 1409 | 639.1 | 4.79 | 2.17 | 8.51 | 3.86 | 8.75 | 3.97 | 1.41 | 0.64 | | |
| | Climbout | 1248 | 566.1 | 4.26 | 1.93 | 5.55 | 2.52 | 2.15 | 0.975 | 1.25 | 0.57 | | |
| | Approach | 645 | 292.6 | 21.48 | 9.74 | 0.568 | 0.258 | 0.0 | 0.0 | 0.65 | 0.29 | | |
| Tyne8.1 RR TP | Idle | 619 | 280.8 | 40.79 | 18.50 | 0.477 | 0.216 | 6.63 | 3.01 | 0.62 | 0.28 | | |
| | Takeoff | 2372 | 1076 | 1.21 | 0.549 | 27.11 | 12.30 | 2.87 | 1.31 | 2.37 | 1.08 | | |
| | Climbout | 2188 | 922.5 | 1.29 | 0.585 | 25.23 | 11.44 | 2.63 | 1.19 | 2.19 | 0.99 | | |
| | Approach | 1095 | 496.7 | 11.30 | 5.13 | 9.00 | 4.08 | 2.68 | 1.22 | 1.10 | 0.50 | | |
| Olympus 593[i] MK610 RR (Bristol) TJ | Idle | 3060 | 1388 | 342.7 | 155.4 | 9.72 | 4.41 | 119.3 | 54.11 | 3.06 | 1.39 | | |
| | Takeoff | 52200 | 23673 | 1513.8 | 686.5 | 542.9 | 246.2 | 151.4 | 68.7 | 52.2 | 23.7 | | |
| | Climbout | 19700 | 8936 | 275.8 | 125.1 | 169.4 | 76.84 | 31.52 | 14.30 | 19.70 | 8.94 | | |
| | Descent | 5400 | 2449 | 426.6 | 193.5 | 18.9 | 8.6 | 132.3 | 60.0 | 5.4 | 2.4 | | |
| | Approach | 9821 | 4455 | 451.8 | 204.9 | 41.25 | 18.71 | 93.30 | 42.32 | 9.82 | 4.46 | | |
| O-200 Con. O | Idle | 8.24 | 3.75 | 5.31 | 2.42 | 0.013 | 0.006 | 0.239 | 0.107 | 0.0 | 0 | | |
| | Takeoff | 45.17 | 20.53 | 44.0 | 20.0 | 0.220 | 0.100 | 0.940 | 0.427 | 0.01 | 0 | | |
| | Climbout | 45.17 | 20.53 | 44.0 | 20.0 | 0.220 | 0.100 | 0.940 | 0.427 | 0.01 | 0 | | |
| | Approach | 25.50 | 11.59 | 30.29 | 13.75 | 0.029 | 0.013 | 0.847 | 0.385 | 0.01 | 0 | | |
| TSIO-360C Con. O | Idle | 11.5 | 5.21 | 6.81 | 3.09 | 0.022 | 0.009 | 1.59 | 0.723 | 0.0 | 0.0 | | |
| | Takeoff | 133. | 60.3 | 143.9 | 65.3 | 0.36 | 0.16 | 1.22 | 0.55 | 0.03 | 0.01 | | |
| | Climbout | 99.5 | 45.1 | 95.6 | 43.4 | 0.43 | 0.20 | 0.95 | 0.43 | 0.02 | 0.01 | | |
| | Approach | 61.0 | 27.7 | 60.7 | 27.5 | 0.23 | 0.10 | 0.69 | 0.31 | 0.01 | 0.01 | | |
| 6-285-B (Tiara) Con. O | Idle | 72.12 | 10.03 | 26.23 | 11.90 | 0.0334 | 0.0152 | 0.773 | 0.350 | 0.0 | 0.0 | | |
| | Takeoff | 153.0 | 69.39 | 152.7 | 69.3 | 0.899 | 0.408 | 1.78 | 0.806 | 0.03 | 0.01 | | |
| | Climbout | 166.0 | 52.61 | 110.9 | 50.3 | 0.913 | 0.414 | 1.39 | 0.632 | 0.02 | 0.01 | | |
| | Approach | 83.5 | 37.88 | 85.39 | 38.77 | 0.394 | 0.179 | 1.343 | 0.609 | 0.02 | 0.01 | | |

TABLE B.1-7 (CONCLUDED)

| Model-Series Mfg.[b] Type[b] | Mode | Fuel Rate lb/hr | Fuel Rate kg/hr | CO lb/hr | CO kg/hr | $NO_x$[c] lb/hr | $NO_x$[c] kg/hr | Total HC[d] lb/hr | Total HC[d] kg/hr | $SO_x$[e] lb/hr | $SO_x$[e] kg/hr | Solid Particulate[f] lb/hr | Solid Particulate[f] kg/hr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| O-320 Lyc. O | Idle | 9.48 | 4.30 | 10.21 | 4.63 | 0.0049 | 0.0022 | 0.350 | 0.159 | 0.0 | 0.0 | | |
| | Takeoff | 89.1 | 40.4 | 96.0 | 43.5 | 0.195 | 0.088 | 1.05 | 0.475 | 0.02 | 0.01 | | |
| | Climbout | 66.7 | 30.3 | 66.0 | 29.9 | 0.265 | 0.120 | 0.826 | 0.375 | 0.01 | 0.01 | | |
| | Approach | 46.5 | 21.1 | 56.8 | 25.8 | 0.044 | 0.020 | 0.895 | 0.406 | 0.01 | 0.0 | | |
| IO-320-DIAD Lyc. O | Idle | 7.84 | 3.56 | 4.86 | 2.20 | 0.009 | 0.0041 | 0.283 | 0.128 | 0.0 | 0.0 | | |
| | Takeoff | 91.67 | 41.57 | 109.3 | 49.55 | 0.167 | 0.0756 | 1.047 | 0.475 | 0.02 | 0.01 | | |
| | Climbout | 61.42 | 27.85 | 54.55 | 24.74 | 0.344 | 0.156 | 0.588 | 0.267 | 0.01 | 0.01 | | |
| | Approach | 37.67 | 17.08 | 35.57 | 16.13 | 0.128 | 0.058 | 0.460 | 0.208 | 0.01 | 0.0 | | |
| IO-360-B Lyc. O | Idle | 8.09 | 3.68 | 7.26 | 3.29 | 0.0094 | 0.0042 | 0.398 | 0.180 | 0.0 | 0.0 | | |
| | Takeoff | 103.0 | 46.7 | 123.5 | 56.0 | 0.205 | 0.093 | 1.03 | 0.469 | 0.02 | 0.01 | | |
| | Climbout | 71.7 | 32.5 | 70.5 | 32.0 | 0.329 | 0.149 | 0.585 | 0.265 | 0.01 | 0.01 | | |
| | Approach | 36.6 | 16.6 | 25.3 | 11.5 | 0.372 | 0.169 | 0.355 | 0.161 | 0.01 | 0.0 | | |
| TIO-540-J2B2 Lyc. O | Idle | 25.06 | 11.36 | 32.42 | 14.70 | 0.0097 | 0.0044 | 1.706 | 0.774 | 0.01 | 0.0 | | |
| | Takeoff | 259.7 | 117.8 | 374.5 | 169.8 | 0.094 | 0.043 | 3.21 | 1.46 | 0.05 | 0.02 | | |
| | Climbout | 204.5 | 92.7 | 300.8 | 136.4 | 0.0481 | 0.0218 | 3.40 | 1.54 | 0.04 | 0.02 | | |
| | Approach | 99.4 | 45.1 | 125.4 | 56.9 | 0.138 | 0.0623 | 1.33 | 0.604 | 0.02 | 0.01 | | |

[a] Refs. 1, 2.

[b] Abbreviations: All – Detroit Diesel Allison Division of General Motors; Con – Teledyne/Continental; GA – Garrett AiResearch; GE – General Electric; Lyc – Avco/Lycoming; P&W – Pratt & Whitney; PWC – Pratt & Whitney Aircraft of Canada; RR – Rolls Royce; TJ – Turbojet; TF – Turbofan ("fanjet"); TP – Turboprop; O – Reciprocating (Piston) Opposed.

[c] Nitrogen oxides reported as $NO_2$.

[d] Total hydrocarbons. Includes unburned hydrocarbons and organic pyrolysis products.

[e] Sulfur oxides and sulfuric acid reported as $SO_2$. Calculated from fuel rate and 0.05 wt% sulfur in Jet A and Jet B fuel, or 0.01 wt% sulfur in aviation gasoline. For turbine engines, the conversion is therefore $SO_x$ (lb/hr) = $10^{-3}$ (fuel rate), and for piston engines, the conversion is $SO_x$ (lb/hr) = $2 \times 10^{-4}$ (fuel rate).

[f] All particulate data are from Ref. 4.

[g] The indicated reference does not specify series number for this model engine.

[h] "Diluted smokeless" JT 8D. Note: JT8D is a turbofan engine and is not equivalent to the JT8 (Military J52) turbojet engine.

[i] All Rolls Royce data are based upon an arbitrary 7% idle which does not reflect the actual situation. In reality, Rolls Royce engines will idle at 5-6% with correspondingly higher emissions (Ref. 20).

[j] The Olympus 593 engine is used in the Concorde SST, which has a unique 6-mode LTO cycle.

## TABLE B.1-8. MODAL EMISSION RATES – MILITARY AIRCRAFT ENGINES[a]

| Model-Series (Civil Version) Mfgr Type[h] | Mode | Fuel Rate | | CO | | $NO_x$[b] | | Total HC[c] | | $SO_x$[d] | | Particulates[e,f] | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | lb/hr | kg/hr | lb/hr | kg/hr | lb/hr | kg/hr | lb/hr | kg/hr | lb/hr | kg/hr | lb/hr | kg/hr |
| J57-P-22 | Idle | 1087 | 493 | 64.4 | 29.2 | 2.7 | 1.2 | 55.8 | 25.3 | 1.1 | 0.5 | 8.3 | 3.8 |
| (JT3C) | Takeoff | 8358 | 3791 | 14.9 | 6.8 | 93.3 | 42.3 | 5.4 | 2.4 | 8.4 | 3.8 | 12.0 | 5.4 |
| P&W TJ | Climbout | 8358 | 3791 | 14.9 | 6.8 | 93.3 | 42.3 | 5.4 | 2.4 | 8.4 | 3.8 | 12.0 | 5.4 |
| | Approach | 1693 | 768 | 39.8 | 18.1 | 5.0 | 2.3 | 21.0 | 9.5 | 1.7 | 0.8 | | |
| J65-W-20 | Idle | 1333 | 605 | 66.9 | 30.3 | 3.7 | 1.7 | 5.0 | 2.3 | 1.3 | 0.6 | | |
| Wr. TJ | Takeoff | 6421 | 2913 | 49.6 | 22.5 | 48.5 | 22.0 | 0.2 | 0.1 | 6.4 | 2.9 | | |
| | Climbout | 6421 | 2913 | 49.6 | 22.5 | 48.5 | 22.0 | 0.2 | 0.1 | 6.4 | 2.9 | | |
| | Approach | 3260 | 1479 | 52.6 | 23.9 | 23.7 | 10.8 | 0.9 | 0.4 | 3.3 | 1.5 | | |
| J79-GE-10 | Idle | 1100 | 499 | 48.0 | 21.8 | 3.2 | 1.5 | 9.8 | 4.4 | 1.1 | 0.5 | 57.8 | 26.2 |
| GE TJ | Takeoff | 35390 | 16053 | 611.9 | 277.6 | 241.3 | 109.5 | 17.2 | 7.8 | 35.4 | 16.1 | 299.7 | 135.9 |
| | Climbout | 9680 | 4482 | 52.0 | 23.6 | 151.8 | 68.9 | 16.0 | 7.3 | 9.9 | 4.5 | 77.7 | 35.2 |
| | Approach | 6190 | 2808 | 45.6 | 20.7 | 69.9 | 31.7 | 4.1 | 1.9 | 6.2 | 2.8 | 67.0 (nom) | 30.4 |
| J85-GE-5F | Idle | 524 | 328 | 93.3 | 42.3 | 0.7 | 0.3 | 15.7 | 7.1 | 0.5 | 0.2 | | |
| GE TJ for T38 | Takeoff | 8470 | 3942 | 245.6 | 111.4 | 22.0 | 10.0 | 6.8 | 3.1 | 8.5 | 3.9 | | |
| | Climbout | 1297 | 588 | 55.8 | 25.3 | 3.0 | 1.4 | 4.5 | 2.0 | 1.3 | 0.6 | | |
| | Approach | 1098 | 498 | 63.7 | 28.9 | 3.0 | 1.4 | 1.3 | 0.6 | 1.1 | 0.5 | | |
| J85-GE-21 | Idle | 400 | 181 | 63.6 | 28.4 | 0.5 | 0.2 | 9.7 | 4.4 | 0.4 | 0.2 | | |
| GE TJ for F-5 | Takeoff | 10650 | 4831 | 387.7 | 175.8 | 59.6 | 27.0 | 1.1 | 0.5 | 10.7 | 4.9 | | |
| | Climbout | 3200 | 1452 | 69.0 | 31.3 | 16.0 | 7.3 | 0.8 | 0.4 | 3.2 | 1.5 | | |
| | Approach | 1200 | 544 | 55.5 | 25.1 | 3.5 | 1.6 | 3.1 | 1.4 | 1.2 | 0.5 | | |
| TF30-P-6B | Idle | 689 | 313 | 47.0 | 21.3 | 0.9 | 0.4 | 12.9 | 5.9 | 0.7 | 0.3 | | |
| (JFT 10) | Takeoff | 6835 | 3100 | 21.1 | 9.6 | 82.3 | 37.3 | 6.9 | 3.1 | 6.8 | 3.1 | | |
| P&W TF | Climbout | 6835 | 3100 | 21.1 | 9.6 | 82.3 | 37.3 | 6.9 | 3.1 | 6.8 | 3.1 | | |
| for A-7 | Approach | 3550 | 1610 | 22.4 | 10.2 | 23.7 | 10.8 | 10.5 | 4.8 | 3.6 | 1.6 | | |
| TF30-P-412A | Idle | 999 | 453 | 68.1 | 30.9 | 2.4 | 1.1 | 38.4 | 17.4 | 1.0 | 0.5 | 26.5 | 12.0 |
| (JFT 10A) | Takeoff | 40000 | 18144 | 600.0 | 272.2 | 270.0 | 122.5 | 40.0 | 18.1 | 40.0 | 18.1 | 693.2 | 314.4 |
| P&W TJ | Climbout | 7394 | 3354 | 15.7 | 7.1 | 123.2 | 55.9 | 0.7 | 0.3 | 7.4 | 3.4 | 61.7 | 29.0 |
| for F-14 | Approach | 2598 | 1178 | 39.5 | 17.9 | 18.4 | 8.3 | 2.9 | 1.3 | 2.6 | 1.2 | 46.6 (nom) | 21.2 |
| TF33-P-3/5/7 | Idle | 846 | 384 | 74.9 | 34.0 | 1.5 | 0.7 | 77.8 | 35.3 | 0.8 | 0.4 | 4.4 | 2.0 |
| (JT3D) | Takeoff | 9979 | 4526 | 13.0 | 5.9 | 109.8 | 49.8 | 3.0 | 1.4 | 10.0 | 4.5 | 79.8 | 36.2 |
| P&W TJ | Climbout | 7323 | 3322 | 13.2 | 6.0 | 65.9 | 29.9 | 2.9 | 1.3 | 7.3 | 3.3 | 102.5 | 46.5 |
| | Approach | 3797 | 1722 | 34.2 | 15.5 | 27.7 | 12.6 | 14.4 | 6.5 | 3.8 | 1.7 | 53.1 | 24.1 |
| TF34-GE-400 | Idle | 457 | 207 | 35.0 | 15.9 | 0.6 | 0.3 | 7.1 | 3.2 | 0.5 | 0.2 | | |
| GE TJ | Takeoff | 3796 | 1722 | 9.3 | 4.2 | 20.9 | 9.5 | 1.6 | 0.7 | 3.8 | 1.7 | | |
| | Climbout | 3796 | 1722 | 9.3 | 4.2 | 20.9 | 9.5 | 1.6 | 0.7 | 3.8 | 1.7 | | |
| | Approach | 1296 | 588 | 19.4 | 8.8 | 10.0 | 4.5 | 0.8 | 0.4 | 1.3 | 0.6 | | |

## TABLE B.1-8 (CONCLUDED)

| Model-Series (Civil-Version) Mfg[h] Type[h] | Mode | Fuel Rate | | CO | | NO[b] | | Total HC[c] | | SO$_x$[d] | | Particulates[e,f] | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | lb/hr | kg/hr | lb/hr | kg/hr | lb/hr | kg/hr | lb/hr | kg/hr | lb/hr | kg/hr | lb/hr | kg/hr |
| TF39-GE-1 | Idle | 1130 | 513 | 75.7 | 34.3 | 3.4 | 1.5 | 26.0 | 11.8 | 1.1 | 0.5 | 0.3[g] | 0.1 |
| (JT4A) | Takeoff | 11410 | 5176 | 8.0 | 3.6 | 319.5 | 144.9 | 2.3 | 1.0 | 11.4 | 5.2 | 17.1[g] | 7.8 |
| GE TJ | Climbout | 5740 | 2604 | 4.0 | 1.8 | 160.7 | 72.9 | 1.1 | 0.5 | 5.7 | 2.6 | 8.0[g] | 3.6 |
| | Approach | 5740 | 2604 | 4.0 | 1.8 | 160.7 | 72.9 | 1.1 | 0.5 | 5.7 | 2.6 | 8.0[g] | 3.6 |
| TF41-A-2 | Idle | 1070 | 485 | 114.6 | 52.0 | 1.4 | 0.6 | 70.8 | 32.1 | 1.1 | 0.5 | | |
| All TF | Takeoff | 9040 | 4101 | 14.4 | 6.5 | 201.4 | 91.4 | 5.3 | 2.4 | 9.0 | 4.1 | | |
| | Climbout | 9040 | 4101 | 14.4 | 6.5 | 201.4 | 91.4 | 5.3 | 2.4 | 9.0 | 4.1 | | |
| | Approach | 5314 | 2410 | 27.5 | 12.5 | 56.6 | 25.7 | 12.9 | 5.9 | 5.3 | 2.4 | | |
| F100-PW-100 | Idle | 1060 | 481 | 20.5 | 9.3 | 4.2 | 1.9 | 2.4 | 1.1 | 1.1 | 0.5 | 0.1[g] | 0.05 |
| (JTF 22) | Takeoff | 44200 | 20049 | 2435.4 | 1104.7 | 729.3 | 330.8 | 4.4 | 2.0 | 44.2 | 20.0 | 0.0[g] | 0.0 |
| P&W TF | Climbout | 10400 | 4717 | 18.7 | 8.5 | 457.6 | 207.6 | 0.5 | 0.2 | 10.4 | 4.7 | 8.6[g] | 3.9 |
| | Approach | 3000 | 1361 | 9.0 | 4.1 | 33.0 | 15.0 | 1.8 | 0.8 | 3.0 | 1.4 | 1.0[g] | 0.5 |
| PT6A-27 | Idle | 115 | 52 | 7.36 | 3.34 | 0.28 | 0.13 | 5.77 | 2.62 | 0.12 | 0.05 | | |
| PWC TP | Takeoff | 425 | 193 | 0.43 | 0.20 | 3.32 | 1.51 | 0 | 0 | 0.43 | 0.20 | | |
| | Climbout | 400 | 181 | 0.48 | 0.22 | 2.80 | 1.27 | 0 | 0 | 0.40 | 0.18 | | |
| | Approach | 215 | 98 | 5.0 | 2.24 | 1.80 | 0.82 | 0.47 | 0.21 | 0.22 | 0.10 | | |
| T56-A7 | Idle | 548 | 249 | 17.5 | 7.9 | 2.1 | 1.0 | 11.5 | 5.2 | 0.5 | 0.2 | 1.6 | 0.7 |
| All TP | Takeoff | 2079 | 943 | 4.4 | 2.0 | 19.3 | 8.8 | 0.8 | 0.4 | 2.1 | 1.0 | 3.7 | 1.7 |
| | Climbout | 1908 | 865 | 4.6 | 2.1 | 17.6 | 8.0 | 0.9 | 0.4 | 0.9 | 0.4 | 3.0 | 1.4 |
| | Approach | 1053 | 478 | 3.7 | 1.7 | 7.8 | 3.5 | 0.5 | 0.2 | 1.1 | 0.5 | 3.0 | 1.4 |
| T53-L-11D | Idle | 142 | 64 | 4.2 | 1.9 | 0.2 | 0.1 | 9.0 | 4.1 | 0.14 | 0.06 | | |
| (LTC1) | Climbout[i] | 679 | 308 | 2.0 | 0.9 | 5.0 | 2.3 | 0.2 | 0.1 | 0.68 | 0.31 | | |
| Lyc TS | Approach | 679 | 308 | 2.0 | 0.9 | 5.0 | 2.3 | 0.2 | 0.1 | 0.68 | 0.31 | | |
| T55-L-11A | Idle | | | 29.5 | 13.4 | 0.8 | 4.0 | 4.0 | 1.8 | | | | |
| (LTC4) | Climbout[i] | | | 14.5 | 6.6 | 18.6 | 8.4 | 0.2 | 0.1 | | | | |
| Lyc TS | Approach | | | 12.9 | 5.9 | 9.1 | 4.1 | 0.3 | 0.1 | | | | |
| T58-GE-5 | Idle | 133 | 60 | 22.5 | 10.2 | 0.2 | 0.1 | 12.9 | 5.9 | 0.1 | 0.05 | 0.1 | 0.05 |
| GE TS | Climbout[i] | 886 | 402 | 5.0 | 2.3 | 6.4 | 2.9 | 0.7 | 0.3 | 0.9 | 0.4 | 0.8 | 0.4 |
| | Approach | 886 | 402 | 5.0 | 2.3 | 6.4 | 2.9 | 0.7 | 0.3 | 0.9 | 0.4 | 0.8 | 0.4 |

[a] Ref. 1.

[b] Nitrogen oxides reported as $NO_2$.

[c] Hydrocarbons (volatile organics). Includes unburned hydrocarbons, and organic pyrolysis products.

[d] Sulfur oxides and sulfuric acid reported as $SO_2$. Calculated from fuel rate and 0.05 wt% sulfur in JP-4 or JP-5 fuel, or 0.01 wt% sulfur in aviation gasoline. For turbine engines, the conversion is therefore $SO_x$ (lb/hr) = $10^{-3}$ (fuel rate), and for piston engines, the conversion is $SO_x$ (lb/hr) = $2 \times 10^{-4}$ (fuel rate).

[e] Includes all "condensible particulates," and, thus may be much higher than solid particulates alone (except as noted in g below).

[f] "Nom." data are interpolated values assumed for calculational purposes, in the absence of experimental data.

[g] Dry particles only.

[h] For abbreviations, cf., footnote, Table B.1-2.

[i] "Takeoff" mode is underfined for helicopters.

TABLE B.1-9. EMISSION FACTORS PER AIRCRAFT PER LANDING-TAKEOFF CYCLE – CIVIL AIRCRAFT[a]

| Commercial Carrier Aircraft | Power Plant[b] No. | Mfg. | Model-Series | CO lb | CO kg | $NO_x$[c] lb | $NO_x$ kg | Total HC[d] lb | Total HC kg | $SO_x$[e] lb | $SO_x$ kg | Particulates lb | Particulates kg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Short, Medium, Long Range and Jumbo Jets** | | | | | | | | | | | | | |
| BAC/Aerospatiale Concorde | 4 | RR | Olymp 593 | 847.0 | 384.0 | 91.0 | 41.0 | 246.0 | 112.0 | 14.1 | 6.4 | | |
| BAC 111-400 | 2 | RR | Spey 511 | 103.36 | 46.88 | 15.04 | 6.82 | 72.42 | 32.85 | 1.70 | 0.77 | 1.46 | 0.66 |
| Boeing 707-320B | 4 | P&W | JT3D-7 | 262.64 | 119.12 | 25.68 | 11.64 | 218.24 | 99.00 | 4.28 | 1.94 | 4.52 | 2.05 |
| Boeing 727-200 | 3 | P&W | JT8D-17 | 55.95 | 25.38 | 29.64 | 13.44 | 13.44 | 6.09 | 3.27 | 1.48 | 1.17 | 0.53 |
| Boeing 737-200 | 2 | P&W | JT8D-17 | 37.30 | 16.92 | 19.76 | 8.96 | 8.96 | 4.06 | 2.18 | 0.99 | 0.78 | 0.35 |
| Boeing 747-200B | 4 | P&W | JT9D-7 | 259.64 | 117.76 | 83.24 | 37.76 | 96.92 | 43.96 | 7.16 | 3.25 | 5.20 | 2.36 |
| Boeing 747-200B | 4 | P&W | JT9D-70 | 108.92 | 49.40 | 107.48 | 48.76 | 22.40 | 10.16 | 7.96 | 3.61 | 5.20 | 2.36 |
| Boeing 747-200B | 4 | RR | RB211-524 | 66.76 | 30.28 | 124.9 | 56.65 | 10.00 | 4.54 | 7.52 | 3.41 | | |
| Lockheed L1011-200 | 3 | RR | RB211-524 | 50.07 | 27.71 | 93.66 | 42.48 | 7.50 | 3.40 | 5.64 | 2.56 | | |
| Lockheed L1011-100 | 3 | RR | RB211-22B | 199.4 | 90.44 | 64.29 | 29.16 | 138.4 | 62.77 | 4.95 | 2.24 | | |
| McDonnell-Douglas DC8-63 | 4 | P&W | JT3D-7 | 262.64 | 119.12 | 25.68 | 11.64 | 218.24 | 99.00 | 3.27 | 1.48 | 1.17 | 0.53 |
| McDonnell-Douglas DC9-50 | 2 | P&W | JT8D-17 | 37.30 | 16.92 | 19.76 | 8.96 | 8.96 | 4.06 | 2.18 | 0.99 | 0.78 | 0.35 |
| McDonnell-Douglas DC10-30 | 3 | GE | CF6-50C | 116.88 | 53.01 | 49.59 | 22.17 | 47.10 | 21.36 | 4.98 | 2.26 | 0.21 | 0.10 |
| **Air Carrier Turboprops – Commuter, Feeder Line and Freighters** | | | | | | | | | | | | | |
| Beech 99 | 2 | PWC | PT6A-28 | 7.16 | 3.25 | 0.82 | 0.37 | 5.08 | 2.30 | 0.18 | 0.08 | | |
| GD/Convair 580 | 2 | All | 501 | 24.38 | 11.06 | 21.66 | 9.82 | 9.82 | 4.45 | 0.92 | 0.42 | | |
| DeHavilland Twin Otter | 2 | PWC | PT6A-27 | 7.16 | 3.25 | 0.82 | 0.37 | 5.08 | 2.30 | 0.18 | 0.08 | | |
| Fairchild F27 and FH227 | 2 | RR | R.Da.7 | 36.26 | 16.45 | 0.92 | 0.42 | 22.42 | 10.17 | 0.58 | 0.26 | | |
| Grumman Goose | 2 | PWC | PT6A-27 | 7.16 | 3.25 | 0.82 | 0.37 | 5.08 | 2.30 | 0.18 | 0.08 | | |
| Lockheed L188 Electra | 4 | All | 501 | 48.76 | 22.12 | 43.32 | 19.65 | 19.64 | 8.91 | 1.84 | 0.83 | | |
| Lockheed L100 Hercules | 4 | All | 501 | 48.76 | 22.12 | 43.32 | 19.65 | 19.64 | 8.91 | 1.84 | 0.83 | | |
| Swearingen Metro-2 | 2 | GA | TPE 331-3 | 6.26 | 2.84 | 1.16 | 0.53 | 7.68 | 3.48 | 0.16 | 0.07 | 0.46 | 0.21 |

TABLE B.1-9 (CONCLUDED)

| General Aviation Aircraft | Power Plant[b] No. | Mfg. | Model-Series | CO lb | CO kg | $NO_x$[c] lb | $NO_x$ kg | Total HC[d] lb | Total HC kg | $SO_x$[e] lb | $SO_x$ kg | Particulates lb | Particulates kg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Business Jets | | | | | | | | | | | | | |
| Cessna Citation | 2 | P&W | JT15D-1 | 19.50 | 8.85 | 2.00 | 0.91 | 6.72 | 3.05 | 0.40 | 0.18 | | |
| Dassault Falcon 20 | 2 | GE | CF700-2D | 76.14 | 34.54 | 1.68 | 0.76 | 7.40 | 3.36 | 0.78 | 0.35 | | |
| Gates Learjet 24D | 2 | GE | CJ610-6 | 88.76 | 40.26 | 1.58 | 0.72 | 8.42 | 3.82 | 0.84 | 0.38 | | |
| Gates Learjet 35, 36 | 2 | GE | TPE 731-2 | 11.26 | 5.11 | 3.74 | 1.58 | 3.74 | 1.70 | 0.92 | 0.42 | | |
| Rockwell International Shoreliner 75A | 2 | GE | CF 700 | 76.14 | 34.54 | 1.08 | 0.76 | 7.40 | 3.36 | 0.78 | 0.35 | | |
| Business Turboprops (EPA Class P2) | | | | | | | | | | | | | |
| Beech B99 Airliner | 2 | PWC | PT6A-27 | 7.16 | 3.25 | 0.82 | 0.37 | 5.08 | 2.30 | 0.18 | 0.08 | | |
| DeHavilland Twin Otter | 2 | PWC | PT6A-27 | 7.16 | 3.25 | 0.82 | 0.37 | 5.08 | 2.30 | 0.18 | 0.08 | | |
| Shorts Skyvan-3 | 2 | GA | TPE-331-2 | 6.44 | 2.92 | 0.883 | 0.400 | 8.40 | 3.81 | 0.16 | 0.07 | 0.46 | 0.21 |
| Swearingen Merlin IIIA | 2 | GA | TPE-331-3 | 6.28 | 2.85 | 1.15 | 0.522 | 7.71 | 3.50 | 0.16 | 0.07 | 0.46 | 0.21 |
| General Aviation Piston (EPA Class P1) | | | | | | | | | | | | | |
| Cessna 150 | 1 | Con | O-200 | 8.32 | 3.77 | 0.02 | 0.01 | 0.23 | 0.10 | 0.0 | 0.0 | | |
| Piper Warrior | 1 | Lyc | O-320 | 14.37 | 6.52 | 0.02 | 0.01 | 0.26 | 0.12 | 0.0 | 0.0 | | |
| Cessna Pressurized Skymaster | 2 | Con | TS10-360C | 33.10 | 15.01 | 0.13 | 0.06 | 1.15 | 0.52 | 0.0 | 0.0 | | |
| Piper Navajo Chieftain | 2 | Lyc | T10-540 | 96.24 | 43.65 | 0.02 | 0.01 | 1.76 | 0.80 | 0.0 | 0.0 | | |

[a] Ref. 2.

[b] Abbreviations: All – Detroit Diesel Allison Division of General Motors; Con – Teledyne/Continental; GA – Garrett AiResearch; GE – General Electric; Lyc – Avco/Lycoming; P&W – Pratt & Whitney; PWC – Pratt & Whitney Aircraft of Canada; RR – Rolls Royce.

[c] Nitrogen oxides reported as $NO_2$.

[d] Total hydrocarbons (volatile organics, including unburned hydrocarbons and organic pyrolysis products.)

[e] Sulfur oxides and sulfuric acid reported as $SO_2$.

# TABLE B.1-10. EMISSION FACTORS PER AIRCRAFT LANDING-TAKEOFF CYCLE – MILITARY AIRCRAFT[a]

| Aircraft | | Power Plant | | TIM[b] | Emissions per LTO Cycle | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | CO | | $NO_x$[c] | | Total HC[d] | | $SO_x$[e] | | Particulates | |
| DOD Desig. | Popular Name | No. | Model - Series | Code | lb | kg | lb | kg | lb | kg | lb | kg | lb | kg |
| Fixed Wing – Turbine | | | | | | | | | | | | | | |
| A-4C | Skyhawk | 1 | J65-W-20 | 2 | 16.62 | 7.54 | 2.15 | 0.98 | 1.10 | 0.50 | 0.46 | 0.21 | | |
| A-7 | Corsair 2 | 1 | TF30-P-6B | 2 | 11.10 | 5.03 | 2.05 | 0.93 | 3.18 | 1.44 | 0.35 | 0.16 | | |
| A-7 | Corsair 2 | 1 | TF41-A-2 | 2 | 25.79 | 11.70 | 4.83 | 2.19 | 15.76 | 7.15 | 0.52 | 0.24 | | |
| B-52H | Stratofortress | 8 | TF-33-P-3/5/8 | 7 | 504.08 | 228.65 | 53.04 | 24.06 | 505.76 | 229.41 | 10.24 | 4.64 | 94.08 | 42.67 |
| F-4 | Phantom 2 | 2 | J79-GE-10 | 2 | 32.24 | 14.62 | 10.88 | 4.94 | 4.94 | 2.24 | 1.46 | 0.66 | 33.92 | 15.39 |
| F-5 | Freedom Fighter/ Tiger 2 | 2 | J85-GE-21 | 1 | 76.64 | 34.76 | 2.10 | 0.95 | 10.04 | 4.55 | 0.76 | 0.34 | | |
| F-14 | Tomcat | 2 | TF30-P-412A | 2 | 39.88 | 18.09 | 7.62 | 3.46 | 17.36 | 7.87 | 1.24 | 0.56 | 24.24 | 11.00 |
| F-15A | Eagle | 2 | F100-PW-100 | 1 | 54.40 | 24.68 | 29.96 | 13.58 | 2.68 | 1.22 | 2.32 | 1.06 | 0.44 | 0.20 |
| F-16 | ---------- | 1 | F100-PW-100 | 1 | 27.20 | 12.34 | 14.98 | 6.79 | 1.34 | 0.61 | 1.16 | 0.53 | 0.22 | 0.10 |
| C-5A | Galaxy | 4 | TF39-GE-1 | 5 | 82.12 | 37.25 | 79.60 | 36.11 | 28.08 | 12.74 | 3.84 | 1.74 | 4.12 | 1.87 |
| C-130 | Hercules | 4 | T56-A-7 | 6 | 32.36 | 14.68 | 9.60 | 4.35 | 20.28 | 9.20 | 1.60 | 0.73 | 4.36 | 1.98 |
| KC-135 | Stratotanker | 4 | J57-P-22 | 7 | 220.92 | 100.21 | 24.64 | 11.18 | 185.56 | 84.17 | 5.36 | 2.43 | 31.36 | 14.22 |
| C-141 | Starlifter | 4 | TF33-P-3/5/7 | 5 | 92.40 | 41.91 | 19.20 | 8.71 | 87.68 | 39.77 | 3.00 | 1.36 | 33.00 | 14.97 |
| T-34C | Turbo Mentor | 1 | PT6A-27 | 2 | 1.73 | 0.78 | 0.15 | 0.07 | 1.27 | 0.58 | 0.03 | 0.01 | | |
| T-38 | Talon | 2 | J85-GE-5F | 3 | 82.72 | 32.99 | 1.22 | 0.55 | 10.42 | 4.73 | 0.62 | 0.82 | | |
| P-3C | Orion | 4 | T56-A-7 | 6 | 32.36 | 14.68 | 9.60 | 4.35 | 20.28 | 9.20 | 1.60 | 0.73 | 4.36 | 1.98 |
| S-3A | Viking | 2 | TF34-GE-400 | 6 | 34.18 | 15.50 | 4.04 | 1.83 | 6.44 | 2.92 | 1.02 | 0.46 | | |
| Helicopters – Turbine | | | | | | | | | | | | | | |
| UH-1H | Iroquois/Huey | 1 | T53-L-11D | 9 | 1.55 | 0.70 | 1.19 | 0.54 | 2.53 | 1.15 | 0.20 | 0.09 | | |
| HH-3 | Sea King/Jolly Green Giant | 2 | T58-GE-5 | 9 | 13.54 | 6.14 | 3.02 | 1.37 | 6.78 | 3.08 | 0.44 | 0.20 | 0.40 | 0.18 |
| CH-47 | Chinook | 2 | T55-L-11A | 9 | 20.94 | 9.50 | 6.68 | 3.03 | 2.10 | 0.96 | | | | |

[a] Ref. 1.

[b] The TIM code is defined in Table B.1-4.

[c] Nitrogen oxides reported as $NO_2$.

[d] "Total hydrocarbons" (volatile organics). Includes unburned hydrocarbons and organic pyrolysis products.

[e] Sulfur oxides and sulfuric acid reported as $SO_2$.

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